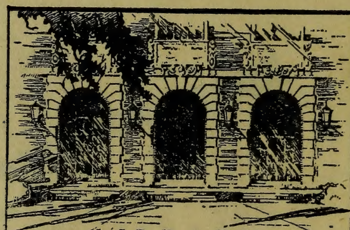
THE COAL AND METAL MINERS' POCKET BOOK



THE COAL AND METAL MINERS' POCKETBOOK

OF

PRINCIPLES, RULES, FORMULAS, AND TABLES.

SPECIALLY COMPILED AND PREPARED FOR THE CONVENIENT USE OF MINE OFFICIALS, MINING ENGINEERS, AND STUDENTS PREPARING THEMSELVES FOR CERTIFICATES OF COMPETENCY AS MINE INSPECTORS OR MINE FOREMEN.

NINTH EDITION: REVISED AND ENLARGED,

WITH

ORIGINAL MATTER.

"Though index learning turns no student pale,
It grasps the Eel ot Science by the tail."
Pope.

SCRANTON, PA.:
INTERNATIONAL TEXTBOOK COMPANY.
1907.

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Preface to Ninth Edition.

In this edition, the principal changes are in the section on wire rope, which has been greatly enlarged by the addition of material treating on cableways, tramways, transmission of power by wire rope, and wire-rope calculations. A glossary of wire-rope terms has been added which has been checked up by the leading wire-rope makers of the United States, and therefore represents the latest practice.

A number of changes have been made in this and previous editions, based on suggestions of users of the Pocketbook. We will appreciate any notice of errors or omissions so that future editions may be made as complete and accurate as possible.

Preface to Eighth Edition.

The eighth edition of The Coal and Metal Miners' Pocketbook is an exact reprint of the seventh edition, issued to supply the demand while the ninth edition was being prepared, and in which a number of changes will be made.

Preface to Seventh Edition.

The speedy exhaustion of the sixth edition of The Coal and Metal Miners' Pocketbook, coupled with a steady and increasing demand for it, has made necessary this seventh edition. In it a few typographical errors which unavoidably occurred (as is the case in every book of this nature and size), have been corrected, all departments have been carefully revised, improved, and brought up to date, and considerable new matter has been added. Thus, the value of the work has been materially increased. The value of suggestions as to improvements in this edition made by users of the sixth edition is acknowledged with thanks, and we request that users of this new, or seventh, edition, will kindly call our attention to any errors or omissions they may discover, so that future editions may be kept fully abreast with the requirements of mining practice as such practice continues to advance.

Preface to Sixth Edition.

The fifth edition of The Coal and Metal Miners' Pocketbook was very kindly received, and the criticisms of it were most friendly and flattering.

The sixth edition has been compiled under particularly favorable circumstances and is much more complete than any previous edition.

Prominent engineers and manufacturers of mining machinery throughout the world have kindly criticized the previous edition, have suggested wherein it could be improved, and have sent to us information from their private note books that has never before been published.

The staff of MINES AND MINERALS, the large force of Mining, Mechanical, and Electrical Engineers connected with The International Correspondence Schools, and many other engineers and mine managers have contributed to it.

All this material has been carefully sifted, verified wherever possible, and combined with the data in the former edition. By careful selection and rewriting, or by different methods of presentation, it has been possible to include essentially all that was in the fifth edition, and at the same time to add from one-third to one-half again as much entirely new matter, without materially increasing the size of the book.

Every portion of the fifth edition has been either entirely rewritten, or revised, enlarged, and brought up to date. New illustrations have been drawn, and the entire book has been printed from new plates.

The sections on Mathematics and Surveying have been amplified by the addition of new tables and by text treating of the Solar Transit and Rocky Mountain methods of surveying.

The sections on Hydraulics; the Application of Electricity to Mining; Timbering, Haulage, Blasting, Ore Dressing, and Coal Washing are entirely new.

The sections on Prospecting, Ventilation, and Methods of Working have been entirely rewritten, enlarged, and greatly improved.

The tables of Logarithms, Trigonometric Functions, etc. have been reset from the latest corrected editions of standard tables. The Traverse Table has been greatly reduced in length, but without affecting its efficiency, while the table of Squares, Cubes, etc. has been added to by the addition of Circumferences and Areas of Circles.

The Glossary, which contains about 2,500 words, is believed to be the most complete mining glossary ever published, as it is a combination of all the mining glossaries extant of which the compilers could hear.

Wherever possible, credit has been given the authorities from whom data have been taken, but in such a work it is manifestly impossible to give full credit for everything that has been extracted, quoted, and compiled, and we can only in this very general way acknowledge our indebtedness to the large number of authors and engineers whom we have failed to mention by name in the text.

No one appreciates as fully as does the editor of such a publication the value of the suggestions and data that have been so generously furnished to assist us in the compilation. We shall be greatly obliged to all readers of this volume who may call our attention to any errors that they may discover, or to the omission of any data that they may feel the lack of, so that attention may be given to these matters in future editions.

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WEIGHTS AND MEASURES.

APPLIED MECHANICS.

FORMS OF POWER.

MINING.

COAL AND METAL MINERS'

POCKETBOOK.

WEIGHTS AND MEASURES.

THE METRIC SYSTEM.

Since the metric system is the adopted system in many countries, and as it is almost universally used in connection with scientific work, a brief description of it is here given as preliminary to the following tables of weights and measures.

The metric system has three principal units:

1. *The meter, or unit of length*, supposed to be the one ten-millionth part of the distance from the equator to the pole on the meridian of longitude passing through the city of Paris. Its actual value is 39.370432 in., the standard authorized by the United States Government being 39.37 in. According to this standard, 1 yd. $= \frac{3{,}600}{3{,}937}$ meter.

2. *The gram, or unit of weight*, is the weight of a cubic centimeter of distilled water at 4° centigrade and 776 millimeters of atmospheric measure. The kilogram (Kg.) = 1,000 grams = 2.2046 lb., is the ordinary unit of weight corresponding to the English pound. According to the United States Government regulations, 1 lb. avoirdupois $= \frac{1}{2.2046}$ kilogram.

3. *The liter, or unit of liquid volume*, is the volume of 1,000 cubic centimeters of distilled water at 4° centigrade and 776 millimeters pressure.

Multiples of these units are obtained by prefixing to the names of the printed units the Greek words *deka* (10), *hekto* (100), *kilo* (1,000). The submultiples or divisions are obtained by prefixing the Latin words *deci* ($\frac{1}{10}$), *centi* ($\frac{1}{100}$), and *milli* ($\frac{1}{1000}$). The abbreviations of these several units as given in the following tables are those commonly used. The kilogram-meter is the work done in raising 1 kg. through a height of 1 m., and equals 7.233 ft.-lb. One metric horsepower (*force de cheval* or *cheval vapeur*) equals .98633 English horsepower.

TROY WEIGHT.

24 grains	= 1 pennyweight.		
20 pennyweights	= 1 ounce	= 480 grains.	
12 ounces	= 1 pound	= 5,760 grains	= 240 pennyweights.

In troy, apothecaries', and avoirdupois weights, the grains are the same.

APOTHECARIES' WEIGHT.

20 grains	= 1 scruple.			
3 scruples	= 1 dram	= 60 grains.		
8 drams	= 1 ounce	= 480 grains	= 24 scruples.	
12 ounces	= 1 pound	= 5,760 grains	= 288 scruples	= 96 drams.

AVOIRDUPOIS WEIGHT.

27.34375 grains	= 1 dram.		
16 drams	= 1 ounce	= 437½ grains.	
16 ounces	= 1 pound	= 7,000 grains	= 256 drams.
28 pounds	= 1 quarter	= 448 ounces.	
4 quarters	= 1 hundredweight	= 112 pounds.	
20 hundredweight	= 1 ton	= 2,240 pounds.	
	1 stone	= 14 pounds.	
	1 quintal	= 100 pounds.	
	1 "short ton"	= 2,000 pounds.	
	1 "long ton"	= 2,240 pounds.	

1 ounce troy or apothecaries'	= 1.09714	avoirdupois ounces.
1 pound troy or apothecaries'	= .82286	avoirdupois pound.
1 ounce avoirdupois	= .911458	troy or apothecaries' ounce.
1 pound avoirdupois	= 1.21528	troy or apothecaries' pounds.

METRIC WEIGHT.

10 milligrams (mg.)	= 1 centigram (cg.)	= .15432	grain.
10 centigrams	= 1 decigram (dg.)	= 1.5432	grains.
10 decigrams	= 1 gram (g.)	= 15.432	grains.
10 grams	= 1 decagram (Dg.)	= .022046	lb. avoir.
10 decagrams	= 1 hectogram (Hg.)	= .22046	lb. avoir.
10 hectograms	= 1 kilogram (Kg.)	= 2.2046	lb. avoir.
10 kilograms	= 1 myriagram (Mg.)	= 22.046	lb. avoir.
10 myriagrams	= 1 quintal (Q.)	= 220.46	lb. avoir.
10 quintals	= 1 tonneau, millier, or tonne	= 2,204	lb. avoir.

MEASURES OF LENGTH.

AMERICAN AND BRITISH.

12 inches	= 1 foot.					
3 feet	= 1 yard	= 36 in.				
6 feet	= 1 fathom	= 2 yd.	= 72 in.			
66 feet	= 1 chain*	= 11 fath.	= 22 yd.	= 792 in.		
10 chains	= 1 furlong	= 110 fath.	= 220 yd.	= 660 ft.	= 7,620 in.	
8 furlongs	= 1 mile	= 80 chains	= 880 fath.	= 1,760 yd.	= 5,280 ft.	= 63,360 in.

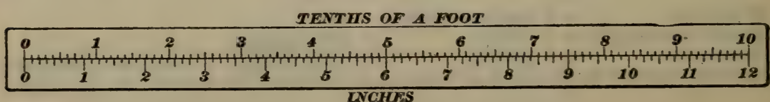
A nautical mile, or knot = 1.15136 statute miles.

A league = 3 nautical miles.

*The chain of 66 ft. is practically obsolete. Chains of 50 or 100 ft. are now used exclusively by American surveyors.

To Reduce Inches to Decimals of a Foot.—Divide the number of inches by 12. Thus, 7 in. = 7 ÷ 12, or .58333 ft. To reduce fractions of inches to decimals of a foot, divide the fraction by 12, and then divide the numerator of the quotient by the denominator. Thus, $\frac{3}{8}$ in. = $\frac{3}{8} \div 12 = \frac{3}{96}$. $\frac{3}{96}$ = .0313 ft.

The annexed scale shows on one side, proportionately reduced, a scale of tenths. On the other, a scale of twelfths, corresponding to inches. To reduce inches to decimal parts of a foot, find the number of inches and



fractional parts thereof on the side marked "inches." Opposite, on the scale of tenths, will be found the decimal part of a foot. Thus, if we want to find the decimal part of a foot represented by 7½ inches, we find the mark corresponding to 7½ inches on the side marked "inches." Opposite this mark we read 6 tenths, 2 hundredths, and 5 thousandths; or, expressed decimally, .625.

DECIMALS OF A FOOT FOR EACH 1-32 OF AN INCH.

Inch.	0″	1″	2″	3″	4″	5″	6″	7″	8″	9″	10″	11″
0	0	.0833	.1667	.2500	.3333	.4167	.5000	.5833	.6667	.7500	.8333	.9167
$\frac{1}{32}$	.0026	.0859	.1693	.2526	.3359	.4193	.5026	.5859	.6693	.7526	.8359	.9193
$\frac{1}{16}$	.0052	.0885	.1719	.2552	.3385	.4219	.5052	.5885	.6719	.7552	.8385	.9219
$\frac{3}{32}$	.0078	.0911	.1745	.2578	.3411	.4245	.5078	.5911	.6745	.7578	.8411	.9245
$\frac{1}{8}$	.0104	.0937	.1771	.2604	.3437	.4271	.5104	.5937	.6771	.7604	.8437	.9271
$\frac{5}{32}$	.0130	.0964	.1797	.2630	.3464	.4297	.5130	.5964	.6797	.7630	.8464	.9297
$\frac{3}{16}$	.0156	.0990	.1823	.2656	.3490	.4323	.5156	.5990	.6823	.7656	.8490	.9323
$\frac{7}{32}$	.0182	.1016	.1849	.2682	.3516	.4349	.5182	.6016	.6849	.7682	.8516	.9349
$\frac{1}{4}$	.0208	.1042	.1875	.2708	.3542	.4375	.5208	.6042	.6875	.7708	.8542	.9375
$\frac{9}{32}$	.0234	.1068	.1901	.2734	.3568	.4401	.5234	.6068	.6901	.7734	.8568	.9401
$\frac{5}{16}$	.0260	.1094	.1927	.2760	.3594	.4427	.5260	.6094	.6927	.7760	.8594	.9427
$\frac{11}{32}$	.0286	.1120	.1953	.2786	.3620	.4453	.5286	.6120	.6953	.7786	.8620	.9453
$\frac{3}{8}$	.0312	.1146	.1979	.2812	.3646	.4479	.5312	.6146	.6979	.7812	.8646	.9479
$\frac{13}{32}$	.0339	.1172	.2005	.2839	.3672	.4505	.5339	.6172	.7005	.7839	.8672	.9505
$\frac{7}{16}$	.0365	.1198	.2031	.2865	.3698	.4531	.5365	.6198	.7031	.7865	.8698	.9531
$\frac{15}{32}$	.0391	.1224	.2057	.2891	.3724	.4557	.5391	.6224	.7057	.7891	.8724	.9557
$\frac{1}{2}$	.0417	.1250	.2083	.2917	.3750	.4583	.5417	.6250	.7083	.7917	.8750	.9583
$\frac{17}{32}$	.0443	.1276	.2109	.2943	.3776	.4609	.5443	.6276	.7109	.7943	.8776	.9609
$\frac{9}{16}$	.0469	.1302	.2135	.2969	.3802	.4635	.5469	.6302	.7135	.7969	.8802	.9635
$\frac{19}{32}$	.0495	.1328	.2161	.2995	.3828	.4661	.5495	.6328	.7161	.7995	.8828	.9661
$\frac{5}{8}$	.0521	.1354	.2188	.3021	.3854	.4688	.5521	.6354	.7188	.8021	.8854	.9688
$\frac{21}{32}$	.0547	.1380	.2214	.3047	.3880	.4714	.5547	.6380	.7214	.8047	.8880	.9714
$\frac{11}{16}$	.0573	.1406	.2240	.3073	.3906	.4740	.5573	.6406	.7240	.8073	.8906	.9740
$\frac{23}{32}$	.0599	.1432	.2266	.3099	.3932	.4766	.5599	.6432	.7266	.8099	.8932	.9766
$\frac{3}{4}$	.0625	.1458	.2292	.3125	.3958	.4792	.5625	.6458	.7292	.8125	.8958	.9792
$\frac{25}{32}$	.0651	.1484	.2318	.3151	.3984	.4818	.5651	.6484	.7318	.8151	.8984	.9818
$\frac{13}{16}$	.0677	.1510	.2344	.3177	.4010	.4844	.5677	.6510	.7344	.8177	.9010	.9844
$\frac{27}{32}$	.0703	.1536	.2370	.3203	.4036	.4870	.5703	.6536	.7370	.8203	.9036	.9870
$\frac{7}{8}$	.0729	.1562	.2396	.3229	.4062	.4896	.5729	.6562	.7396	.8229	.9062	.9896
$\frac{29}{32}$	.0755	.1589	.2422	.3255	.4089	.4922	.5755	.6589	.7422	.8255	.9089	.9922
$\frac{15}{16}$	.0781	.1615	.2448	.3281	.4115	.4948	.5781	.6615	.7448	.8281	.9115	.9948
$\frac{31}{32}$	.0807	.1641	.2474	.3307	.4141	.4974	.5807	.6641	.7474	.8307	.9141	.9974

METRIC SYSTEM.

10 millimeters (mm.)	= 1 centimeter (cm.)	=	.3937079	inch.
10 centimeters	= 1 decimeter (dm.)	=	3.937079	inches.
10 decimeters	= 1 meter (m.)	=	3.2808992	feet.
10 meters	= 1 decameter (Dm.)	=	10.9363	yards.
10 decameters	= 1 hectometer (Hm.)	=	109.363	yards.
10 hectometers	= 1 kilometer (Km.)	=	.6213824	mile.
10 kilometers	= 1 myriameter (Mm.)	=	6.213824	miles.

RUSSIAN.

12 inches = 1 foot = 1 American foot.
7 feet = 1 sachine, or sagene.
500 sachine = 1 verst = 3,500 feet.

PRUSSIAN, DANISH, AND NORWEGIAN.

12 inches = 1 foot = 1.02972 American feet.
12 feet = 1 ruth = 12.35664 American feet.
2,000 ruths = 1 mile = 4.68+ American miles.

AUSTRIAN.

12 inches = 1 foot = 1.03713 American feet.
6 feet = 1 klafter.
4,000 klafters = 1 mile = 4.71+ American miles.

SWEDISH.

12 inches = 1 foot = .97410 American foot.
6 feet = 1 fathom.
6,000 fathoms = 1 mile = 6.64+ American miles.

CHINESE.

1 chih = 1.054 American feet.
10 chih = 1 chang = 10.54 American feet.
180 chang = 1 li = 1,897 American feet.

MEASURES OF AREA.

AMERICAN AND BRITISH.

144 sq. inches = 1 square foot.
9 sq. feet = 1 square yard = 1,296 sq. in.
$30\frac{1}{4}$ sq. yards = 1 perch = $272\frac{1}{4}$ sq. ft.
40 perches = 1 rood = 1,210 sq. yd. = 10,890 sq. ft.
4 roods = 1 acre = 160 perches = 4,840 sq. yd. = 43,560 sq. ft.
640 acres = 1 square mile.

TABLE FOR REDUCING SQUARE FEET TO ACRES.

Square Feet.	Acres.	Square Feet.	Acres.	Square Feet.	Acres.	Square Feet.	Acres.
100,000,000	2,295.684						
90,000,000	2,066.116	900,000	20.661	9,000	.207	90	.0021
80,000,000	1,836.547	800,000	18.365	8,000	.184	80	.0018
70,000,000	1,606.979	700,000	16.070	7,000	.161	70	.0016
60,000,000	1,377.410	600,000	13.774	6,000	.138	60	.0014
50,000,000	1,147.842	500,000	11.478	5,000	.115	50	.0011
40,000,000	918.274	400,000	9.183	4,000	.092	40	.0009
30,000,000	688.705	300,000	6.887	3,000	.069	30	.0007
20,000,000	459.137	200,000	4.591	2,000	.046	20	.0005
10,000,000	229.568	100,000	2.296	1,000	.023	10	.0002
9,000,000	206.612	90,000	2.066	900	.021	9	.00021
8,000,000	183.655	80,000	1.836	800	.018	8	.00018
7,000,000	160.698	70,000	1.607	700	.016	7	.00016
6,000,000	137.741	60,000	1.377	600	.014	6	.00014
5,000,000	114.784	50,000	1.148	500	.011	5	.00011
4,000,000	91.827	40,000	.918	400	.009	4	.00009
3,000,000	68.870	30,000	.689	300	.007	3	.00007
2,000,000	45.914	20,000	.459	200	.005	2	.00005
1,000,000	22.957	10,000	.230	100	.0023	1	.00002

METRIC SYSTEM.

1 square millimeter (sq. mm.) = .001550 sq. in.
1 square centimeter (sq. cm.) = .155003 sq. in.
1 square decimeter (sq. dm.) = 15.5003 sq. in.
1 square meter, or centare ($m.^2$ or sq. m.) = 10.764101 sq. ft.
1 square decameter, or are (sq. Dm.) = .024711 acre.
1 hectare (ha.) = 2.47110 acres.
1 square kilometer (sq. Km.) = 247.110 acres.
1 square myriameter (sq. Mm.) = 38.61090 sq. mi.

MEASURES OF VOLUME.

AMERICAN AND BRITISH.

1,728 cubic inches = 1 cubic foot.
27 cubic feet = 1 cubic yard.

A cord of wood = 128 cu. ft., or a pile of wood 8 ft. long, 4 ft. wide, and 4 ft. high = 1 cord. A perch of masonry contains 24¾ cu. ft.; but in practice it is taken as 25 cu. ft.

A ton (2,240 lb.) of Pennsylvania anthracite, when broken for domestic use, occupies about 42 cu. ft. of space; bituminous coal, about 46 cu. ft.; and coke, about 88 cu. ft. A bushel of coal is 80 lb. in Kentucky, Illinois, and Missouri, 76 lb. in Pennsylvania, 70 lb. in Indiana, and 76 lb. in Montana.

METRIC SYSTEM.

1 milliliter, or cu. centimeter (cc. or $cm.^3$)	=	.0610254	cu. in.
1 centiliter (cl.)	=	.610254	cu. in.
1 deciliter (dl. or $dl.^3$)	=	6.10254	cu. in.
1 liter, or cu. decimeter (l.)	=	61.0254	cu. in.
1 decaliter, or centistere (Dl. or dal.)	=	.353156	cu. ft.
1 hectoliter, or decistere (Hl.)	=	3.53156	cu. ft.
1 kiloliter, or cu. meter, or stere (Kl. or $cm.^3$)	=	35.3156	cu. ft.
1 myrialiter, or decastere (Ml.)	=	353.156	cu. ft.

LIQUID MEASURE (U. S.).

4 gills	= 1 pint	= 16 liquid oz.	= 28.876	cu. in.
2 pints	= 1 quart	= 8 gills	= 57.75	cu. in.
4 quarts	= 1 gallon	= 32 gills = 8 pints	= 231	cu. in.
31½ gallons	= 1 barrel	= 7,276½ cu. in.	= 4.21	cu. ft.
63 gallons	= 1 hogshead.			
2 hogsheads	= 1 pipe.			
2 pipes	= 1 tun.			

A box 19⅜ in. on each side contains 1 barrel.
1 cu. ft. = 7.48 gallons.

DRY MEASURE (U. S.).

2 pints	= 1 quart	= 67.2006 cu. in.	= 1.16365 liquid qt.
4 quarts	= 1 gallon	= 268.8025 cu. in.	= 1.16365 liquid gal.
2 gallons	= 1 peck	= 8 quarts	= 537.6050 cu. in.
4 pecks	= 1 bushel	= 64 pints	= 32 quarts = 8 gal. = 2,150.42 cu. in.

BRITISH IMPERIAL MEASURE, BOTH LIQUID AND DRY.

4 gills	= 1 pint	= 34.6592	cu. in.
2 pints	= 1 quart	= 69.3185	cu. in.
4 quarts	= 1 gallon	= 277.274	cu. in.
8 quarts	= 1 peck	= 554.548	cu. in.
4 pecks	= 1 bushel	= 2,218.192	cu. in.

The standard U. S. bushel is the Winchester bushel, which is in cylinder form, 18½ inches diameter and 8 inches deep, and contains 2,150.42 cubic inches.

The British Imperial bushel is based on the Imperial gallon and contains 8 such gallons, or 2,218.192 cubic inches = 1.2837 cubic feet.

Capacity of a cylinder in U. S. gallons = square of diameter in inches × height in inches × .0034 (accurate within 1 part in 100,000).

Capacity of a cylinder in U. S. bushels = square of diameter in inches × height in inches × .0003652.

CONTENTS OF CYLINDERS OR PIPES FOR 1 FOOT IN LENGTH.

The contents of pipes or cylinders in gallons or pounds are to each other as the squares of their diameters. Thus, a pipe 9 ft. in diameter will contain 9 times as much as a 3′ pipe, or 4 times as much as a 4½′ pipe.

DIAMETERS IN INCHES.

Diam. in Inches.	Diameter in Decimals of a Foot.	Gallons of 231 Cu. In. (U. S. Standard.)	Weight of Water in Lb. in 1 Ft. of Length.	Diam. in Inches.	Diameter in Decimals of a Foot.	Gallons of 231 Cu. In. (U. S. Standard.)	Weight of Water in Lb. in 1 Ft. of Length.
¼	.0208	.0025	.02122	5	.4167	1.020	8.488
½	.0417	.0102	.08488	5½	.4583	1.234	10.270
¾	.0625	.0230	.19098	6	.5000	1.469	12.223
1	.0833	.0408	.33952	6½	.5417	1.724	14.345
1¼	.1042	.0638	.53050	7	.5833	1.999	16.636
1½	.1250	.0918	.76392	7½	.6250	2.295	19.098
1¾	.1458	.1249	1.0398	8	.6667	2.611	21.729
2	.1667	.1632	1.3581	8½	.7083	2.948	24.530
2¼	.1875	.2066	1.7188	9	.7500	3.305	27.501
2½	.2083	.2550	2.1220	9½	.7917	3.682	30.641
2¾	.2292	.3085	2.5676	10	.8333	4.080	33.952
3	.2500	.3672	3.0557	10½	.8750	4.498	37.432
3½	.2917	.4998	4.1591	11	.9167	4.937	41.082
4	.3333	.6528	5.4323	11½	.9583	5.396	44.901
4½	.3750	.8263	6.8750	12	1.0000	5.875	48.891

DIAMETERS IN FEET.

1¼	1.25	9.18	76.392	10	10.00	587.6	4,889.12
1½	1.50	13.22	110.00	10½	10.50	647.7	5,404.24
1¾	1.75	17.99	149.73	11	11.00	710.9	5,915.84
2	2.00	23.50	195.56	11½	11.50	777.0	6,485.72
2¼	2.25	29.74	247.51	12	....	846.1	7,040.00
2½	2.50	36.72	305.57	13	....	992.8	8,710.00
2¾	2.75	44.43	369.74	14	....	1,152.0	10,096.00
3	3.00	52.88	440.00	15	....	1,322.0	11,000.50
3¼	3.25	65.28	544.37	16	....	1,504.0	12,516.00
3½	3.50	71.97	631.00	17	....	1,698.0	14,166.00
3¾	3.75	82.62	687.53	18	....	1,904.0	15,841.00
4	4.00	94.0	782.24	19	....	2,121.0	17,691.00
4¼	4.25	106.1	885.40	20	....	2,350.0	19,556.50
4½	4.50	119.0	990.04	21	....	2,591.0	21,617.00
4¾	4.75	132.5	1,105.71	22	....	2,844.0	23,663.00
5	5.00	146.9	1,222.28	23	....	3,108.0	25,943.00
5¼	5.25	161.9	1,351.06	24	....	3,384.0	28,160.00
5½	5.50	177.7	1,478.96	25	....	3,672.0	30,557.00
5¾	5.75	194.3	1,621.43	26	....	3,971.0	34,840.00
6	6.00	211.5	1,760.00	27	....	4,283.0	35,641.00
6¼	6.25	229.5	1,915.18	28	....	4,606.0	40,384.00
6½	6.50	248.2	2,177.48	29	....	4,941.0	41,117.00
6¾	6.75	267.7	2,233.96	30	....	5,288.0	44,002.00
7	7.00	287.9	2,524.00	31	....	5,646.0	46,984.00
7½	7.50	330.5	2,750.12	32	....	6,017.0	50,064.00
8	8.00	376.0	3,128.96	33	....	6,398.0	53,242.00
8½	8.50	424.5	3,541.60	34	....	6,792.0	56,664.00
9	9.00	475.9	3,960.16	35	....	7,197.0	59,891.50
9½	9.50	530.2	4,422.84	36	....	7,614.0	63,364.00

MEXICAN, CENTRAL AMERICAN, AND SOUTH AMERICAN WEIGHTS AND MEASURES.

The following table gives weights and measures in commercial use in Mexico and the republics of Central and South America, and their equivalents in the United States. Published by the Bureau of the American Republics.

Denomination.	Where Used.	U. S. Equivalents.
Arobe	Paraguay	25 pounds.
Arroba (dry)	Argentine Republic	25.3175 pounds.
Arroba (dry)	Brazil	32.38 pounds.
Arroba (dry)	Cuba	25.3664 pounds.
Arroba (dry)	Venezuela	25.4024 pounds.
Arroba (liquid)	Cuba and Venezuela	4.263 gallons.
Barril	Argentine Republic and Mexico	20.0787 gallons.
Carga	Mexico and Salvador	300 pounds.
Centavo	Central America	4.2631 gallons.
Cuadra	Argentine Republic	4.2 acres.
Cuadra	Paraguay	78.9 yards.
Cuadra (square)	Paraguay	8.077 square feet.
Cuadra	Uruguay	2 acres (nearly).
Fanega (dry)	Central America	1.5745 bushels.
Fanega (dry)	Chile	2.575 bushels.
Fanega (dry)	Cuba	1.599 bushels.
Fanega (dry)	Mexico	1.54728 bushels.
Fanega (dry)	Uruguay (double)	7.776 bushels.
Fanega (dry)	Uruguay (single)	3.888 bushels.
Fanega (dry)	Venezuela	1.599 bushels.
Frasco	Argentine Republic	2.5096 quarts.
Frasco	Mexico	2.5 quarts.
League (land)	Paraguay	4,633 acres.
Libra	Argentine Republic	1.0127 pounds.
Libra	Central America	1.043 pounds.
Libra	Chile	1.014 pounds.
Libra	Cuba	1.0161 pounds.
Libra	Mexico	1.01465 pounds.
Libra	Peru	1.0143 pounds.
Libra	Uruguay	1.0143 pounds.
Libra	Venezuela	1.0161 pounds.
Livre	Guiana	1.0791 pounds.
Manzana	Costa Rica	$1\frac{5}{8}$ acres.
Marc	Bolivia	.507 pound.
Pie	Argentine Republic	.9478 foot.
Quintal	Argentine Republic	101.42 pounds.
Quintal	Brazil	130.06 pounds.
Quintal	Chile, Mexico, and Peru	101.61 pounds.
Quintal	Paraguay	100 pounds.
Vara	Argentine Republic	34.1208 inches.
Vara	Central America	38.874 inches.
Vara	Chile and Peru	33.367 inches.
Vara	Cuba	33.384 inches.
Vara	Mexico	33 inches.
Vara	Paraguay	34 inches.
Vara	Venezuela	33.384 inches.

CONVERSION TABLES.

(*United States Coast and Geodetic Survey.*)

The method of using the following tables for converting United States weights and measures into metric weights and measures will be understood by the following example:

Find the number of kilometers in 125 miles.

From column "Miles to Kilometers," 1 mile = 1.60935 kilometers, or 100 miles = 160.935 kilometers; 2 miles = 3.21869 kilometers, or 20 miles = 32.1869 kilometers; and 5 miles = 8.04674 kilometers. Hence, 125 miles = 160.935 + 32.1869 + 8.04674 = 201.16864 kilometers.

CUSTOMARY TO METRIC.

LINEAR.

	Inches to Millimeters.	Feet to Meters.	Yards to Meters.	Miles to Kilometers.
1	25.4	0.304801	0.914402	1.60935
2	50.8	0.609601	1.828804	3.21869
3	76.2	0.914402	2.743205	4.82804
4	101.6	1.219202	3.657607	6.43739
5	127.0	1.524003	4.572009	8.04674
6	152.4	1.828804	5.486411	9.65608
7	177.8	2.133604	6.400813	11.26543
8	203.2	2.438405	7.315215	12.87478
9	228.6	2.743205	8.229616	14.48412

CAPACITY.

	Fluid Drams to Milliliters, or Cubic Centimeters.	Fluid Ounces to Milliliters.	Quarts to Liters.	Gallons to Liters.
1	3.70	29.57	0.94636	3.78543
2	7.39	59.15	1.89272	7.57087
3	11.09	88.72	2.83908	11.35630
4	14.79	118.29	3.78543	15.14174
5	18.48	147.87	4.73179	18.92717
6	22.18	177.44	5.67815	22.71261
7	25.88	207.02	6.62451	26.49804
8	29.57	236.59	7.57087	30.28348
9	33.27	266.16	8.51723	34.06891

SQUARE.

	Square Inches to Square Centimeters.	Square Feet to Square Decimeters.	Square Yards to Square Meters.	Acres to Hectares.
1	6.452	9.290	0.836	0.4047
2	12.903	18.581	1.672	0.8094
3	19.355	27.871	2.508	1.2141
4	25.807	37.161	3.344	1.6187
5	32.258	46.452	4.181	2.0234
6	38.710	55.742	5.017	2.4281
7	45.161	65.032	5.853	2.8328
8	51.613	74.323	6.689	3.2375
9	58.065	83.613	7.525	3.6422

WEIGHT.

	Grains to Milligrams.	Avoirdupois Ounces to Grams.	Avoirdupois Pounds to Kilograms.	Troy Ounces to Grams.
1	64.7989	28.3495	0.45359	31.10348
2	129.5978	56.6991	0.90719	62.20696
3	194.3968	85.0486	1.36078	93.31044
4	259.1957	113.3981	1.81437	124.41392
5	323.9946	141.7476	2.26796	155.51740
6	388.7935	170.0972	2.72156	186.62088
7	453.5924	198.4467	3.17515	217.72437
8	518.3914	226.7962	3.62874	248.82785
9	583.1903	255.1457	4.08233	279.93133

CUBIC.

	Cubic Inches to Cubic Centimeters.	Cubic Feet to Cubic Meters.	Cubic Yards to Cubic Meters.	Bushels to Hectoliters.
1	16.387	.02832	0.765	0.35239
2	32.774	.05663	1.529	0.70479
3	49.161	.08495	2.294	1.05718
4	65.549	.11327	3.058	1.40957
5	81.936	.14158	3.823	1.76196
6	98.323	.16990	4.587	2.11436
7	114.710	.19822	5.352	2.46675
8	131.097	.22654	6.116	2.81914
9	147.484	.25485	6.881	3.17154

MISCELLANEOUS.

1 Gunter's chain	=	20.1168 meters.
1 sq. statute mile	=	259.000 hectares.
1 fathom	=	1.829 meters.
1 nautical mile	=	1,853.25 meters.
1 ft. = .304801 meter		9.4840158 log.
1 avoir. pound	=	453.5924277 gram.
15,432.35639 grains	=	1 kilogram.

The method of using the following tables for converting metric weights and measures into United States weights and measures may be understood by the following example:

Find the number of yards in 86 meters.

From column "Meters to Yards," 8 meters = 8.748889 yards, or 80 meters = 87.48889 yards; and 6 meters = 6.561667 yards. Hence, 86 meters = 87.48889 + 6.561667 = 94.050557 yards.

METRIC TO CUSTOMARY.

LINEAR.

	Meters to Inches.	Meters to Feet.	Meters to Yards.	Kilometers to Miles.
1	39.37	3.28083	1.093611	0.62137
2	78.74	6.56167	2.187222	1.24274
3	118.11	9.84250	3.280833	1.86411
4	157.48	13.12333	4.374444	2.48548
5	196.85	16.40417	5.468056	3.10685
6	236.22	19.68500	6.561667	3.72822
7	275.59	22.96583	7.655278	4.34959
8	314.96	26.24667	8.748889	4.97096
9	354.33	29.52750	9.842500	5.59233

CAPACITY.

	Milliliters, or Cubic Centiliters to Fluid Drams.	Centiliters to Fluid Ounces.	Liters to Quarts.	Decaliters to Gallons.	Hectoliters to Bushels.
1	0.27	0.338	1.0567	2.6417	2.8377
2	0.54	0.676	2.1134	5.2834	5.6755
3	0.81	1.014	3.1700	7.9251	8.5132
4	1.08	1.353	4.2267	10.5668	11.3510
5	1.35	1.691	5.2834	13.2085	14.1887
6	1.62	2.029	6.3401	15.8502	17.0265
7	1.89	2.367	7.3968	18.4919	19.8642
8	2.16	2.705	8.4535	21.1336	22.7019
9	2.43	3.043	9.5101	23.7753	25.5397

SQUARE.

	Square Centimeters to Square Inches.	Square Meters to Square Feet.	Square Meters to Square Yards.	Hectares to Acres.
1	0.155	10.764	1.196	2.471
2	0.310	21.528	2.392	4.942
3	0.465	32.292	3.588	7.413
4	0.620	43.055	4.784	9.884
5	0.775	53.819	5.980	12.355
6	0.930	64.583	7.176	14.826
7	1.085	75.347	8.372	17.297
8	1.240	86.111	9.568	19.768
9	1.395	96.875	10.764	22.239

WEIGHT.

	Milligrams to Grains.	Kilograms to Grains.	Hectograms to Ounces Avoir.	Kilograms to Pounds Avoir.
1	.01543	15,432.36	3.5274	2.20462
2	.03086	30,864.71	7.0548	4.40924
3	.04630	46,297.07	10.5822	6.61387
4	.06173	61,729.43	14.1096	8.81849
5	.07716	77,161.78	17.6370	11.02311
6	.09259	92,594.14	21.1644	13.22773
7	.10803	108,026.49	24.6918	15.43236
8	.12346	123,458.85	28.2192	17.63698
9	.13889	138,891.21	31.7466	19.84160

CUBIC.

	Cubic Centimeters to Cubic Inches.	Cubic Decimeters to Cubic Inches.	Cubic Meters to Cubic Feet.	Cubic Meters to Cubic Yards.
1	.0610	61.023	35.314	1.308
2	.1220	122.047	70.629	2.616
3	.1831	183.070	105.943	3.924
4	.2441	244.094	141.258	5.232
5	.3051	305.117	176.572	6.540
6	.3661	366.140	211.887	7.848
7	.4272	427.164	247.201	9.156
8	.4882	488.187	282.516	10.464
9	.5492	549.210	317.830	11.771

WEIGHT—(*Continued*).

	Quintals to Pounds Avoir.	Milliers, or Tonnes to Pounds Avoir.	Kilograms to Ounces Troy.
1	220.46	2,204.6	32.1507
2	440.92	4,409.2	64.3015
3	661.39	6,613.9	96.4522
4	881.85	8,818.5	128.6030
5	1,102.31	11,023.1	160.7537
6	1,322.77	13,227.7	192.9044
7	1,543.24	15,432.4	225.0552
8	1,763.70	17,637.0	257.2059
9	1,984.16	19,841.6	289.3567

METRIC CONVERSION TABLE.

(*Arranged by C. W. Hunt, New York.*)

Millimeters × .03937 = in.
Millimeters ÷ 25.4 = in.
Centimeters × .3937 = in.
Centimeters ÷ 2.54 = in.
Meters × 39.37 = in. (Act Congress).
Meters × 3.281 = ft.
Meters × 1.094 = yd.
Kilometers × .621 = miles.
Kilometers ÷ 1.6093 = miles.
Kilometers × 3,280.7 = ft.
Square millimeters × .0155 = sq. in.
Square millimeters ÷ 645.1 = sq. in.
Square centimeters × .155 = sq. in.
Square centimeters ÷ 6.451 = sq. in.
Square meters × 10.764 = sq. ft.
Square kilometers × 247.1 = acres.
Hectare × 2.471 = acres.
Cubic centimeters ÷ 16.383 = cu. in.
Cubic centimeters ÷ 3.69 = fluid drams (U. S. P.).
Cubic centimeters ÷ 29.57 = fluid oz. (U. S. P.).
Cubic meters × 35.315 = cu. ft.
Cubic meters × 1.308 = cu. yd.
Cubic meters × 264.2 = gal. (231 cu. in.).
Liters × 61.022 = cu. in. (Act Congress).
Liters × 33.84 = fluid oz. (U. S. Phar.).
Liters × .2642 = gal. (231 cu. in.).
Liters ÷ 3.78 = gal. (231 cu. in.).
Liters ÷ 28.316 = cu. ft.
Tonnes × 1.102 = short tons.
Tonnes × .9839 = long tons.
Hectoliters × 3.531 = cu. ft.
Hectoliters × 2.84 = bu. (2,150.42 cu. in.).
Hectoliters × .131 = cu. yd.
Hectoliters ÷ 26.42 = gal. (231 cu. in.).
Grams × 15.432 = gr. (Act Congress).
Grams ÷ 981 = dynes.
Grams (water) ÷ 29.57 = fluid oz.
Grams ÷ 28.35 = oz. avoir.
Grams per cu. cent. ÷ 27.7 = lb. per cu. in.
Joule × .7373 = ft.-lb.
Kilograms × 2.2046 = lb.
Kilograms × 35.3 = oz. avoir.
Kilograms ÷ 1,102.3 = ton (2,000 lb.).
Kilogr. per sq. cent. × 14.223 = lb. per sq. in.
Kilogram-meters × 7.233 = ft.-lb.
Kilo per meter × .672 = lb. per ft.
Kilo per cu. meter × .026 = lb. per cu. ft.
Kilo per cheval × 2.235 = lb. per H. P.
Kilowatts × 1.34 = H. P.
Watts ÷ 746 = H. P.
Watts ÷ .7373 = ft.-lb. per sec.
Calorie × 3.968 = B. T. U.
Cheval vapeur × .9863 = H. P.
(Centigrade × 1.8) + 32 = degree F.
Franc × .193 = dollars.
Gravity Paris = 980.94 centimeters per sec.

MONEY.

UNITED STATES CURRENCY.

10 mills	=	1 cent.
10 cents	=	1 dime.
10 dimes	=	1 dollar.
10 dollars	=	1 eagle.

BRITISH MONEY.

4 farthings	=	1 penny.
12 pence	=	1 shilling.
20 shillings	=	1 pound sterling.
21 shillings	=	1 guinea.

STANDARD UNITED STATES COINS.

Gold.			Silver.		
Denomination.	Value.	Weight.	Denomination.	Value.	Weight.
* Dollar	$1.00	25.8 gr.	* Trade dollar...	$1.00	420.0 gr.
Quarter eagle	2.50	64.5 gr.	Standard silver dollar	1.00	412.5 gr.
* Three-dollar piece	3.00	77.4 gr.	Half dollar	.50	192.9 gr.
Half eagle	5.00	129.0 gr.	Quarter dollar...	.25	96.45 gr.
Eagle	10.00	258.0 gr.	Dime	.10	38.58 gr.
Double eagle	20.00	516.0 gr.			

"Fineness" expresses the proportion of pure metal in 1,000 parts; thus, "900 fine" means that 900 of every 1,000 parts are pure metal. Fineness of

* No longer coined.

U. S. coins = 900 pure metal, 100 alloy; alloy of gold coin is copper or copper and silver, but in no case shall silver exceed $\frac{1}{10}$ of total alloy. Alloy of silver coin is copper.

Piece.	*Weight.*	*Contents.*
5-cent (nickel)	77.16 grains	75% copper, 25% nickel.
*3-cent	30 grains	75% copper, 25% nickel.
*2-cent	66 grains	95% copper, 5% tin and zinc.
1-cent (copper)	48 grains	95% copper, 5% tin and zinc.

*No longer coined.

Space Required to Store U. S. Coins.

Description.	Amount.	How Put Up.	Space.
Gold coins	$1,000,000	$5,000 in 8-oz. duck bags	Nearly 17 cu. ft.
Silver dollars	1,000,000	1,000 in 8-oz. duck bags	250 cu. ft.
Subsidiary silver	1,000,000	1,000 in 8-oz. duck bags	150 cu. ft.

A bag of standard silver dollars occupies a space 12 in. × 9 in. × 4 in.

To Convert Value of U. S. Coins Into English Values and Vice Versa.

Rule.—*Cents (U. S.) ÷ 2.02771, or × .49312 = English pence.*
Example.— 100 cents × .49312 = 49.312 pence = 4s. 1.312d.
Rule.—*English pence × 2.02771 = cents (U. S.).*
Example.— 100d. × 2.02771 = 202.771 cents = $2.0277.
Rule.— $\frac{\textit{Dollars}}{4.8665}$ = *pounds sterling.*
Example.— $\frac{\$100}{4.8665}$ = £20.548. £.548 × 240 = 131.5d. = 10s. 11.5d.
Rule.—*Pounds × 4.8665 = dollars (U. S.). Shillings × 24.332+ = cents (U. S.).*

VALUES OF FOREIGN COINS, U. S. TREASURY DEPT., JAN. 1, 1899.

Argentine, Argentine Republic	$ 4.824
Bolivar, Venezuela	.193
Boliviano, Bolivia	.439
Centen, Cuba	5.017
Colon, Costa Rica	.465
Condor, Chile	7.300
Condor, U. S. of Colombia and Ecuador	9.647
Copeck, Russia	.0075
Crown, Austria-Hungary	.203
Crown, Denmark, Norway, and Sweden	.268
Crown, Germany	1.06
Crown, Great Britain	1.13
Crown, Sicily	.96
Crown, Spain (half pistole)	1.95
Dollar, Bolivia	.96
†Dollar, British Honduras, British Possessions, N. A. (except Newfoundland), and Liberia	1.000
Dollar, Chile, Peru, and Ecuador	.93
Dollar, Mexican (gold)	.983
Dollar, Mexican (silver)	.477
Dollar, Newfoundland	1.014
Dollar, U. S. of Colombia	.935
Doubloon, Central America	$14.50
Doubloon, Chile	3.650
Doubloon, New Granada	15.34
Doubloon, Spain and Mexico	15.65
Drachma, Greece	.193
Ducat, Austria, Bohemia, Hamburg, Hanover	2.28
Ducat, Denmark	1.11
Ducat, Sweden	2.20
Escudo, Chile	1.825
Florin, Austria-Hungary	1.929
Florin, Hanover (gold)	1.66
Florin, Hanover (silver)	.56
Florin, Holland, South Germany	.38
Florin, Netherlands	.402
Florin, Prussia	.55
Florin, Silesia	.48
Franc, Belgium, Bulgaria, France, Italy, Roumania, Switzerland	.193
Gourde, Hayti	.965
Groschen, Prussian Poland	.024
Guinea, Great Britain	5.11
Gulden, Baden	.40
Imperial, Russia	7.92
Kran, Persia	.081
Kreutzer, Bavaria	.0067

†The British dollar has the same legal value as the Mexican dollar in Hongkong, the Straits Settlements, and Labuan.

VALUES OF FOREIGN COINS.—(*Continued.*)

Lira, Italy	$ .193
Mark, Finland	.193
Mark, German Empire	.238
Maximilian, Bavaria	3.30
Milreis, Brazil	.546
Milreis, Portugal	1.080
Mohur, India	7.105
Napoleon, France	3.84
Peseta, Spain	.193
Peso, Argentine Republic	.965
Peso, Chile	.365
Peso, U. S. of Colombia	.439
Peso, Cuba	.926
Peso, Guatemala, Honduras, Nicaragua, Salvador	.365
Peso, Uruguay	1.034
Piaster, Egypt	.049
Piaster, Turkey	.044
Piastre, Spain	1.04
Pistole, Rome	3.37
Pistole, Spain	3.90
Pound, Egypt	4.943
Pound Sterling, Great Britain	4.8665
Ruble, Russia	.515
Rupee, India	$ .208
Shilling, Great Britain	.243
Sol, Peru	.439
Sou, France	.01
Sovereign, Great Britain	4.8665
Sucre, Ecuador	.439
Tael, China: Amoy	.710
Tael, China: Canton	.708
Tael, China: Chefoo	.679
Tael, China: Chin Kiang	.693
Tael, China: Fuehau	.656
Tael, China: Haikwan (Customs)	.722
Tael, China: Hankow	.664
Tael, China: Hongkong	†
Tael, China: Niuchwang	.665
Tael, China: Ningpo	.682
Tael, China: Shanghai	.648
Tael, China: Swatow	.655
Tael, China: Takau	.714
Tael, China: Tientsin	.688
Toman, Persia	3.409
Yen, Japan	.498

† The British dollar has the same legal value as the Mexican dollar in Hongkong, the Straits Settlements, and Labuan.

The **carat** (a 24th part) is used to express the proportion of gold in an alloy; thus, gold 18 carats fine is $\frac{18}{24}$ pure. The carat is also a unit of weight for precious stones. Its value varies according to different authorities, but the international carat is 3.168 grains, or 206 milligrams.

Diamond Weight (Nystrom).

Carats.		*Grains.*		*Parts.*		*Grains, Troy.*
1	=	4	=	64	=	3.2 (3.168)
.25	=	1	=	16	=	.8
.015625	=	.0625	=	1	=	.05
.3125	=	1.25	=	20	=	1
151.5	=					1 ounce

TIMBER AND BOARD MEASURE.

TIMBER MEASURE.

Volume of Round Timber.—The volume in cubic feet equals the length multiplied by one-fourth the product of mean girth and diameter, all dimensions being in feet. If length is given in feet and girth and diameter in inches, divide by 144; if all dimensions are in inches, divide by 1,728.

Volume of Square Timber.—When all dimensions are in feet:

Rule.—*Multiply the breadth by the depth and that product by the length, and the product will give the volume in cubic feet.*

When either of the dimensions is in inches:

Rule.—*Multiply as above and divide by 12.*

When any two of the dimensions are in inches:

Rule.—*Multiply as before and divide by 144.*

ROUND TIMBER.—TABLE OF ¼ GIRTHS.

¼ Girths. Inches.	Area in Feet.	¼ Girths. Inches.	Area in Feet.	¼ Girths. Inches.	Area in Feet.
6	.250	12¼	1.04	19	2.50
6¼	.272	12½	1.08	19½	2.64
6½	.294	12¾	1.12	20	2.77
6¾	.317	13	1.17	20½	2.91
7	.340	13¼	1.21	21	3.06
7¼	.364	13½	1.26	21½	3.20
7½	.390	13¾	1.31	22	3.36
7¾	.417	14	1.36	22½	3.51
8	.444	14¼	1.41	23	3.67
8¼	.472	14½	1.46	23½	3.83
8½	.501	14¾	1.51	24	4.00
8¾	.531	15	1.56	24½	4.16
9	.562	15¼	1.61	25	4.34
9¼	.594	15½	1.66	25½	4.51
9½	.626	15¾	1.72	26	4.69
9¾	.659	16	1.77	26½	4.87
10	.694	16¼	1.83	27	5.06
10¼	.730	16½	1.89	27½	5.25
10½	.766	16¾	1.94	28	5.44
10¾	.803	17	2.00	28½	5.64
11	.840	17¼	2.09	29	5.84
11¼	.878	17½	2.12	29½	6.04
11½	.918	17¾	2.18	30	6.25
11¾	.959	18	2.25		
12	1.000	18½	2.37		

Area corresponding to ¼ girth (mean) in inches multiplied by length in feet equal solidity in feet and decimal parts.

BOARD MEASURE.

In measuring boards, they are assumed to be 1 inch in thickness. The number of feet, board measure (B. M.), in a given board or stick of timber, equals the length in feet multiplied by the breadth in feet multiplied by the thickness in inches.

Breadth. Inches.	Area of a Lineal Foot.	Breadth. Inches.	Area of a Lineal Foot.	Breadth. Inches.	Area of a Lineal Foot.
¼	.021	4¼	.354	8¼	.688
½	.042	4½	.375	8½	.708
¾	.063	4¾	.396	8¾	.729
1	.083	5	.417	9	.750
1¼	.104	5¼	.438	9¼	.771
1½	.125	5½	.458	9½	.792
1¾	.146	5¾	.479	9¾	.813
2	.167	6	.500	10	.833
2¼	.188	6¼	.521	10¼	.854
2½	.208	6½	.542	10½	.875
2¾	.229	6¾	.563	10¾	.896
3	250	7	.583	11	.917
3¼	.271	7¼	.604	11¼	.938
3½	.292	7½	.625	11½	.958
3¾	.313	7¾	.646	11¾	.979
4	.333	8	.667	12	1.000

Area of a lineal foot multiplied by length in feet will give superficial contents in square feet.

MATHEMATICS.

By Edward H. Williams, Jr., E. M.

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GENERAL PRINCIPLES.

Quantity or *magnitude* is anything that can be increased or decreased, or that is capable of any sort of measurement or calculation, such as numbers, lines, space, time, motion, weight, force, power, heat, light, electricity, etc. We can measure a quantity by applying to it a portion of the same quantity, called a *unit.* If the quantities are of different kinds, we cannot measure them by one another, but we can compare them or institute a calculation between them.

Mathematics treats of all kinds of quantity that can be numbered or measured. *Arithmetic* is that part that treats of numbering, and is called the science of numbers. *Geometry* is the science of measuring. These two are the foundation of all other parts of mathematics, and are called *pure mathematics.* We can also reason about numbers by substituting letters for numbers, and represent their relations by signs. This is called *algebra*, and it may be likened to a *shorthand* arithmetic. An extension of arithmetic to geometry, by which angles and triangles are subjected to numerical computation, is called *trigonometry*, and *plane trigonometry* treats of methods of computing plane angles and triangles, and embraces the investigations of the relations of angles in general, which is called *angular analysis.* Another extension of arithmetic to geometry, by which lines, areas, and volumes are computed, is called *mensuration.* Mensuration of large portions of the earth's surface, where the curvature of the same is taken into calculation, is called *geodesy.* If the portions are smaller and curvature is neglected, the science is called *surveying*, and *mine surveying* if confined to underground work.

COMMONLY USED MATHEMATICAL SIGNS AND ABBREVIATIONS.

$+$	means *plus*, or *addition.*
$-$	means *minus*, or *subtraction.*
$\times$	means *multiplication.*
$\pm$	means *plus* or *minus.*
$\mp$	means *minus* or *plus.*
$\div$	means *division.*
$:$	means *ratio.*
$: \, :: \, :$	means *proportion.* 2 : 3 : : 4 : 6 shows that *2 is to 3 as 4 is to 6.*
$=$	means *equality.*
≑	means *equivalency.*
$\sqrt{\ }$	means *square root.*
$\sqrt[3]{\ }$	means *cube root*, etc.
$\sqrt{3}$	*square root of 3.*
$\sqrt[3]{5}$	*cube root of 5.*
7^2	*7 squared.*
8^3	*8 cubed.*
$\frac{a}{b}$	$= a/b$, $a \div b$. $15 \div 16 = \frac{15}{16}$.
$\therefore$	*therefore.*
$>$	*greater than.*
$<$	*less than.*
$\square$	*square.*
$\square'$	*square feet.*

$\square''$	*square inches.*
$\bigcirc$	*round.*
( ) [ ] { },	*vincula*, denoting that the numbers enclosed are to be taken together; as, $(a+b)c = \overline{4+3} \times 5 = 35.$
$^\circ$	*degrees, arc* or *thermometer.*
$'$	*minutes* or *feet.*
$''$	*seconds* or *inches.* $30^\circ\ 40'\ 4''$ is *30 degrees 40 minutes 4 seconds.*
$4'\ 6''$	is *4 feet 6 inches.*
$'\ ''\ '''$	*accents to distinguish letters*, as a', a'', a'''.
a_1, a_2, a_b, a_c,	read *a sub 1, a sub b*, etc.
a^2, a^3	*a squared, a cubed.*
$a^{\frac{2}{3}}$	$= \sqrt[3]{a^2}$; $a^{\frac{3}{2}} = \sqrt{a^3}$.
$\sin a$	$=$ *the sine of a.*
log	$=$ *logarithm.*
$\angle$	*angle.*
∟	*right angle.*
$\perp$	*perpendicular to.*
sin	*sine.*
cos	*cosine.*

MATHEMATICAL SIGNS AND ABBREVIATIONS—(*Continued*).

tan, or tang, *tangent.*
sec *secant.*
versin *versed sine.*
cot *cotangent.*
cosec *cosecant.*
covers *coversed sine.*
π *pi, ratio of circumference of circle to diameter* 3.14159.
g *acceleration due to gravity* = (32.16 ft. per sec.).
R, r *radius.*
W, w *weight.*
H. P. *horsepower.*
I. H. P. *indicated horsepower.*
B. H. P. *brake horsepower.*
A. W. G. *American wire gauge* (Brown & Sharpe).
B. W. G. *Birmingham wire gauge.*
r. p. m., or rev. per min., *revolutions per minute.*
A *decimal point* is a period (.) prefixed to a number to show that the number is less than unity (1); thus, $.2 = \frac{2}{10}$; $.35 = \frac{35}{100}$; $5.75 = 5\frac{75}{100}$, or $5\frac{3}{4}$.

ARITHMETIC.

To Cast the Nines Out of a Number.—Add together the digits, and find how many nines are contained in their sum. Reject these nines and set down the remainder to the right of the number.

EXAMPLE.—Cast the nines out of 18,304. 18,304. 7. Ans.

To Prove Addition.—Cast the nines out of each row of figures added, and out of their sum. Add together the remainder and cast the nines from its sum. If the remainder from this last process is equal to the remainder obtained from the sum of the numbers, the addition is correct.

EXAMPLE.—Prove this addition:

2,143,568	2
8,560,391	5
10,703,959	7. Ans.

To Prove Subtraction.—Add the remainder to the lesser number; their sum should equal the larger number.

To Prove Multiplication.—Cast the nines out of multiplicand and multiplier, and multiply the remainders together. Cast the nines out of the product, and the remainder should equal the remainder obtained by casting the nines from the original product.

EXAMPLE.—Prove this multiplication: $3{,}542 \times 6{,}196 = 21{,}946{,}232$.

3,542	5
6,196	4
21,946,232	2. Ans.

To Prove Division.—Subtract the remainder, if there be any, from the dividend, and divide what remains by the quotient. If the new quotient equals the old divisor, the work is right.

EXAMPLE.—Divide 31,046,835 by 56. $554{,}407\frac{43}{56}$. Ans.

PROOF.—Take 43 from 31,046,835, and divide the remainder, 31,046,792, by 554,407. 56. Ans.

Rule.—*To square any number containing the fraction* $\frac{1}{2}$, *multiply the whole number by the next higher whole number, and add* $\frac{1}{4}$.

EXAMPLE.— $(8\frac{1}{2})^2 = 8 \times 9 + \frac{1}{4} = 72\frac{1}{4}$.

COMMON FRACTIONS.

A **fraction** is a part of a whole, as $\frac{1}{2}$, $\frac{2}{3}$, etc.

The **numerator** of a fraction is the number that tells how many parts of a whole are taken. Thus, 2 is the numerator of $\frac{2}{3}$, as it shows that two of the three parts into which the whole is divided are taken.

The **denominator** of a fraction is the number that shows into how many parts the whole is divided. Thus, in the fraction $\frac{2}{3}$, the 3 is the denominator.

A **common denominator** is a denominator common to two or more fractions. Thus, $\frac{1}{4}$ and $\frac{3}{4}$ have common denominators; and again, 12 is a common denominator for $\frac{1}{6}$, $\frac{1}{3}$, $\frac{1}{4}$, and $\frac{1}{2}$, as they each are respectively equal to $\frac{2}{12}$, $\frac{4}{12}$, $\frac{3}{12}$, and $\frac{6}{12}$.

To Add Common Fractions.—If of the same denominator, add together the numerators only. Thus $\frac{1}{16} + \frac{3}{16} + \frac{5}{16} = \frac{9}{16}$.

If they have different denominators, change them to fractions with common denominators, and proceed as before.

EXAMPLE.—What is the sum of $\frac{1}{3}+\frac{1}{4}+\frac{1}{5}$?

$$\frac{1}{3}=\frac{20}{60},\ \frac{1}{4}=\frac{15}{60},\text{ and }\frac{1}{5}=\frac{12}{60}.$$

$$\frac{20}{60}+\frac{15}{60}+\frac{12}{60}=\frac{47}{60}.\ \text{Ans.}$$

To Multiply Common Fractions.—Multiply the numerators together for the numerator, and the denominators for the denominator. Thus, $\frac{1}{2}\times\frac{3}{16}\times\frac{2}{3}=\frac{6}{96}$, or $\frac{1}{16}$.

To Divide Common Fractions.—Invert the divisor, and multiply.

EXAMPLE.—Divide $\frac{9}{64}$ by $\frac{2}{5}$.

$$\frac{9}{64}\times\frac{5}{2}=\frac{45}{128}.\ \text{Ans.}$$

To Reduce Compound Fractions to Simple Fractions.—Multiply the integer by the denominator of the fraction, add the numerator for the new numerator, and place it over the denominator.

EXAMPLE.—Reduce $5\frac{2}{3}$ to a simple fraction.

$5\times3+2=17$, or the numerator, and the fraction is therefore $\frac{17}{3}$.

To Reduce Simple Fractions to Compound Fractions.—Divide the numerator by the denominator, and use the remainder as the numerator of the remaining fraction.

EXAMPLE.—Reduce $\frac{64}{9}$ to a compound fraction.

```
9 ) 64 ( 7
    63      Compound fraction = 7 1/9.  Ans.
    --
     1
```

To Reduce Common Fractions to Decimal Fractions.—Annex ciphers to the numerator, and divide by the denominator, and point off as many decimal places in the quotient as there are ciphers annexed.

EXAMPLE.—Reduce $\frac{9}{16}$ to a decimal fraction.

```
16 ) 9.0000 (.5625  Ans.
     80
     ---
     100
      96
     ---
       40
       32
       --
        80
        80
        --
```

NOTE.—Ciphers annexed to a decimal do not increase its value. 1.13 is the same as 1.1300. Every cipher placed between the first figure of a decimal and the decimal point divides the decimal by 10. Thus,

$$.13\div10=.013.$$

TABLE OF FRACTIONS REDUCED TO DECIMALS.

$\frac{1}{64}$	.015625	$\frac{17}{64}$	.265625	$\frac{33}{64}$	.515625	$\frac{49}{64}$	.765625
$\frac{1}{32}$	.03125	$\frac{9}{32}$	.28125	$\frac{17}{32}$	.53125	$\frac{25}{32}$	.78125
$\frac{3}{64}$	.046875	$\frac{19}{64}$	.296875	$\frac{35}{64}$	.546875	$\frac{51}{64}$	.796875
$\frac{1}{16}$	.0625	$\frac{5}{16}$	.3125	$\frac{9}{16}$	.5625	$\frac{13}{16}$	.8125
$\frac{5}{64}$	.078125	$\frac{21}{64}$	.328125	$\frac{37}{64}$	.578125	$\frac{53}{64}$	.828125
$\frac{3}{32}$	.09375	$\frac{11}{32}$	.34375	$\frac{19}{32}$	.59375	$\frac{27}{32}$	.84375
$\frac{7}{64}$	.109375	$\frac{23}{64}$	.359375	$\frac{39}{64}$	.609375	$\frac{55}{64}$	.859375
$\frac{1}{8}$	.125	$\frac{3}{8}$	.375	$\frac{5}{8}$	.625	$\frac{7}{8}$	.875
$\frac{9}{64}$	.140625	$\frac{25}{64}$	.390625	$\frac{41}{64}$	.640625	$\frac{57}{64}$	.890625
$\frac{5}{32}$	.15625	$\frac{13}{32}$	.40625	$\frac{21}{32}$	.65625	$\frac{29}{32}$	.90625
$\frac{11}{64}$	.171875	$\frac{27}{64}$	.421875	$\frac{43}{64}$	.671875	$\frac{59}{64}$	.921875
$\frac{3}{16}$	.1875	$\frac{7}{16}$	.4375	$\frac{11}{16}$	.6875	$\frac{15}{16}$	.9375
$\frac{13}{64}$	.203125	$\frac{29}{64}$	.453125	$\frac{45}{64}$	.703125	$\frac{61}{64}$	.953125
$\frac{7}{32}$	.21875	$\frac{15}{32}$	.46875	$\frac{23}{32}$	.71875	$\frac{31}{32}$	.96875
$\frac{15}{64}$	.234375	$\frac{31}{64}$	.484375	$\frac{47}{64}$	.734375	$\frac{63}{64}$	.984375
$\frac{1}{4}$	.25	$\frac{1}{2}$	.5	$\frac{3}{4}$	.75	1	1.0000

DECIMALS.

Decimal fractions have for their denominators 10 or a power of 10, but the denominator is usually omitted. Thus, $.1=\frac{1}{10}$; $.01=\frac{1}{100}$; $.001=\frac{1}{1000}$, etc.

To Add Decimals.—Place whole numbers under whole numbers, tenths under tenths, hundredths under hundredths, etc., and add, placing the decimal point in the sum directly under the points above. Thus,

```
  .0075
  .63
 1.06
17.9342
-------
19.6317
```

To Subtract Decimals.—Arrange the figures as in addition, and proceed as in simple subtraction. Thus

$$\begin{array}{r} 5.96978 \\ 3.28694 \\ \hline 2.68284 \end{array}$$

To Multiply Decimals.—Proceed as in simple multiplication, pointing off as many decimal places in the result as there are decimal places in both multiplicand and multiplier. Thus

$$\begin{array}{rl} 4.67531 & \text{(5 decimal places)} \\ .053 & \text{(3 decimal places)} \\ \hline 1402593 & \\ 2337655 & \\ \hline 0.24779143 & \text{(8 decimal places)} \end{array}$$

To Divide Decimals.—Proceed as in simple division, and point off as many decimal places in the quotient as the number of decimal places in the dividend exceeds those in the divisor.

EXAMPLE 1.—Divide 4.756 by 3.3.

$$\begin{array}{l} 3.3\,)\,4.75600\,(\,1.4412 \quad \text{Ans.} \\ \quad\;\; 33 \\ \quad\;\; \overline{145} \\ \quad\;\; 132 \\ \quad\;\; \overline{\;\;186} \\ \quad\;\;\;\; 132 \\ \quad\;\;\;\; \overline{\;\;\;\;40} \\ \quad\;\;\;\;\;\;\;\; 33 \\ \quad\;\;\;\;\;\;\;\; \overline{\;\;\;\;70} \\ \quad\;\;\;\;\;\;\;\;\;\; 66 \\ \quad\;\;\;\;\;\;\;\;\;\; \overline{\;\;\;\;4} \end{array}$$

EXAMPLE 2.—Divide .006 by 20

$$\begin{array}{l} 20\,).0060\,(.0003. \quad \text{Ans.} \\ \qquad\quad 60 \\ \qquad\quad \overline{} \end{array}$$

NOTE.—It has been said before that *algebra is a shorthand arithmetic.* Before proceeding further with the various methods of arithmetic, the principles of algebra will be stated, and, after the subsequent examples are worked out by arithmetical rules, an example will be given of the algebraic method of doing the same. In every example, we have *known* quantities from which we seek to find certain *unknown* ones. While there is no way of indicating these in *arithmetic*, we can readily do so in *algebra*, by placing the first letters of the alphabet as representatives of the known quantities (as a, b, c), and the last letters (x, y, z) of the unknown ones. The signs in algebra are those just given for arithmetic. In addition to them, we can indicate multiplication by placing a period (.) between the quantities, as $a.b$ (read *a multiplied by b*), or simply by placing the two letters together, as ab. We can indicate division as in common fractions, $\frac{a}{b}$ being read *a divided by b.*

To illustrate algebraic symbols, let l denote the length, b the breadth, and h the height of a mine car. If it be desired to divide the height into the product of the length and breadth, it is expressed as follows:

$$\frac{lb}{h}.$$

When two or more letters are placed together, without anything between them, it is understood that the quantities represented by those letters should be multiplied together. If l represents 8 and b represents 4, then 4 and 8 are multiplied together; thus, $4 \times 8 = 32$.

If it be desired to divide the height into the sum of the length and breadth, it is expressed thus:

$$\frac{l+b}{h}.$$

The square of the length multiplied by the cube of the breadth, thus:

$$l^2 b^3.$$

The square root of the length divided by the cube root of the breadth, thus:

$$\frac{\sqrt{l}}{\sqrt[3]{b}}.$$

The square root of the difference of the length and breadth divided by the height, thus:

$$\frac{\sqrt{l-b}}{h}.$$

SIMPLE PROPORTION, OR SINGLE RULE OF THREE.

A **proportion** is an expression of equality between equal ratios; thus, the ratio of 10 to 5 = the ratio of 4 to 2, and is expressed thus:

$$10 : 5 :: 4 : 2.$$

There are four terms in proportion. The first and last are the *extremes*, and the second and third are the *means*.

Quantities are in proportion by *alternation* when antecedent is compared with antecedent and consequent with consequent. Thus, if 10 : 5 :: 4 : 2, then 10 : 4 :: 5 : 2.

Quantities are in proportion by *inversion* when the antecedents are made consequents and the consequents antecedents. Thus, if 10 : 5 :: 4 : 2, then 5 : 10 :: 2 : 4.

In any proportion, the product of the means will equal the product of the extremes. Thus, if 10 : 5 :: 4 : 2, then $5 \times 4 = 10 \times 2$.

A mean proportional between two quantities equals the square root of their product. Thus, a mean proportional between 12 and 3 = the square root of 12×3, or 6.

If the two means and one extreme of a proportion are given, we find the other extreme by dividing the product of the means by the given extreme. Thus, 10 : 5 :: 4 : ( ), then $(4 \times 5) \div 10 = 2$, and the proportion is 10 : 5 :: 4 : 2.

If the two extremes and one mean are given, we find the other mean by dividing the product of the extremes by the given mean. Thus, 10 : ( ) :: 4 : 2, then $(10 \times 2) \div 4 = 5$, and the proportion is 10 : 5 :: 4 : 2.

EXAMPLE.—If 6 men load 30 wagons of coal in a day, how many wagons will 10 men load? (They will evidently load more, so the second term of the proportion must be greater than the first.)

6 : 10 :: 30 : ( ); then, $(10 \times 30) \div 6 = 50$. Ans.

COMPOUND PROPORTION, OR DOUBLE RULE OF THREE.

PRINCIPLES.

1. The product of the simple ratios of the first couplet equals the product of the simple ratios of the second couplet. Thus,

$$\left\{\begin{matrix}4 : 12\\7 : 14\end{matrix}\right\} :: \left\{\begin{matrix}5 : 10\\6 : 18\end{matrix}\right\} = \frac{4}{12} \times \frac{7}{14} = \frac{5}{10} \times \frac{6}{18}.$$

2. The product of all the terms in the extremes equals the product of all the terms in the means. Thus, in

$$\left\{\begin{matrix}4 : 12\\7 : 14\end{matrix}\right\} :: \left\{\begin{matrix}5 : 10\\6 : 18\end{matrix}\right\}$$

we have $4 \times 7 \times 10 \times 18 = 12 \times 14 \times 5 \times 6.$

3. Any term in either extreme equals the product of the means divided by the product of the other terms in the extremes. Thus, in the same proportion, we have

$$4 = \frac{5 \times 6 \times 12 \times 14}{7 \times 10 \times 18}.$$

4. Any term in either mean equals the product of the extremes divided by the product of the other terms in the means. Thus, in

$$\left\{\begin{matrix}4 : 12\\7 : 14\end{matrix}\right\} :: \left\{\begin{matrix}5 : 10\\6 : 18\end{matrix}\right\}$$

we have $5 = (4 \times 7 \times 10 \times 18) \div (6 \times 12 \times 14).$

Rule.—I. *Put the required quantity for the first term and the similar known quantity for the second term, and form ratios with each pair of similar quantities for the second couplet, as if the result depended on each pair and the second term.*

II. *Find the required term by dividing the product of the means by the product of the fourth terms.*

EXAMPLE 1.—If 4 men can earn $24 in 7 days, how much can 14 men earn in 12 days?

The sum : \$24 :: $\left\{\begin{matrix}14 : 4\\12 : 7\end{matrix}\right\}$; or, the sum $= \frac{24 \times 14 \times 12}{4 \times 7} = \$144$. Ans.

EXAMPLE 2.—If 12 men in 35 days build a wall 140 rd. long, 6 ft. high, how

many men can, in 40 days, build a wall of the same thickness 144 rd. long, 5 ft. high?

$$\left\{\begin{matrix} 40:35 \\ 140:144 \\ 6:5 \end{matrix}\right\} :: 12 : (\ ) = \frac{35 \times 144 \times 5 \times 12}{40 \times 140 \times 6} = 9. \quad \text{Ans.}$$

INVOLUTION.

To Square a Number.—Multiply the number by itself. Thus, the square of $4 = 4 \times 4$, or 16.

To Cube a Number.—Multiply the square of the number by the number. Thus, the cube of $4 = 16 \times 4 = 64$.

To Find the Fourth Power of a Number.—Multiply the cube by the number. Thus, the fourth power of $4 = 64 \times 4 = 256$.

To Raise a Number to the Sixth Power.—Square its cube.

To Raise a Number to the Twelfth Power.—Square its sixth power.

(See logarithms for shorter method.)

EVOLUTION.

To Find the Square Root of a Number:

Rule.—I. *Separate the given number into periods of two figures each, beginning at the units place.*

II. *Find the greatest number whose square is contained in the period on the left; this will be the first figure in the root. Subtract the square of this figure from the period on the left, and to the remainder annex the next period to form a dividend.*

III. *Divide this dividend, omitting the figure on the right, by double the part of the root already found, and annex the quotient to that part, and also to the divisor; then, multiply the divisor thus completed by the figure of the root last obtained, and subtract the product from the dividend.*

IV. *If there are more periods to be brought down, continue the operation as before.*

EXAMPLE.—Find the square root of 874,225.

```
        8 7'4 2'2 5 ( 9 3 5   Ans.
        8 1
18  3 | 6 4 2
        5 4 9
186  5 | 9 3 2 5
         9 3 2 5
```

OPERATION.

$9 \times 2 = 18$. 18 into 64 goes 3 times, hence new divisor = 183. $93 \times 2 = 186$. 186 into 932 goes 5 times, hence new divisor = 1,865.

(See logarithms for shorter method.)

The square root of a fraction is found by extracting the square root of the numerator and denominator separately. Thus, the square root of $\frac{9}{64} = \frac{3}{8}$.

When decimals occur, the number is pointed off into periods both right and left from the decimal point, and there will be as many decimal places in the root as there are periods to the right of the decimal point in the number.

EXAMPLE 1.—Find the square root of 874.225.

```
        8'7 4.2 2'5 ( 2 9.5 6+
        4
 4 9 | 4 7 4
       4 4 1
 5 8  5 | 3 3 2 2
          2 9 2 5
 5 9 0  7 | 3 9 7 5 0
            3 5 4 4 2
            4 3 0 8+
```

EXAMPLE 2.—Find the square root of .00874225.

```
       .0 0'8 7'4 2'2 5 (.0 9 3 5
            8 1
 1 8  3 |   6 4 2
            5 4 9
 1 8 6  5 | 9 3 2 5
            9 3 2 5
```

To Find the Cube Root of a Number:

Rule.—I. *Separate the given number into periods of three figures each, beginning at the units place.*

II. *Find the greatest number whose cube is contained in the period on the left; this will be the first figure in the root. Subtract the cube of this figure from the period on the left, and to the remainder annex the next period to form a dividend.*

III. *Divide this dividend by the partial divisor, which is 3 times the square of the root already found, considered as tens; the quotient is the second figure of the root.*

IV. *To the partial divisor add 3 times the product of the second figure of the root by the first considered as tens, also the square of the second figure, the result will be the complete divisor.*

V. *Multiply the complete divisor by the second figure of the root, and subtract the product from the dividend.*

VI. *If there are more periods to be brought down, proceed as before, using the part of the root already found, the same as the first figure in the previous process.*

EXAMPLE.—Find the cube root of 12,812,904.

OPERATION.

		12,812,904 (234 Ans.
	$2^3 =$	8
1st partial divisor, $3 \times 20^2 =$	1,200	4,812
$3 \times 20 \times 3 =$	180	
$3^2 =$	9	4,167
1st complete divisor,	1,389	645,904
2d partial divisor, $3 \times 230^2 =$	158,700	
$3 \times 230 \times 4 =$	2,760	
$4^2 =$	16	645,904
2d complete divisor,	161,476	

The cube root of a fraction is found by extracting the cube root of the numerator and denominator separately. Thus, the cube root of $\frac{27}{64} = \frac{3}{4}$.

(See logarithms for shorter method.)

PERCENTAGE.

Percentage means by or on the hundred. Thus, $1\% = \frac{1}{100} = .01$, $3\% = \frac{3}{100} = .03$.

To Find the Percentage, Having the Rate and the Base.—Multiply the base by the rate expressed in hundredths. Thus 6% of 1,930 is found as follows:

$$1{,}930 \times .06 = 115.80.$$

To Find the Amount, Having the Base and the Rate.—Multiply the base by 1 plus the rate. Thus, the amount of \$1,930 for one year at 6% is $\$1{,}930 \times 1.06 = \$2{,}045.80$.

To Find the Base, Having the Rate and the Percentage.—Divide the percentage by the rate. Thus, if the rate is 6% and the percentage is 115.80, the base $= 115.80 \div .06 = 1{,}930$.

To Find the Rate, Having the Percentage and the Base.—Divide the percentage by the base. Thus, if the percentage is 115.80 and the base 1,930, the rate equals $115.80 \div 1{,}930 = .06$, or 6%.

ARITHMETICAL PROGRESSION.

Quantities are said to be in *arithmetical progression* when they increase or decrease by a common difference. The following is an increasing series in arithmetical progression: 1, 3, 5, 7, 9, 11, 13. If the figures be read backward, 13, 11, 9, etc., it becomes a decreasing series. In the first series, the *first term* is 1; the *last term* 13; the *number of terms* 7; the *common difference* 2; and the *sum* of the terms 49.

In any arithmetical progression,

Let $f =$ first term;
$l =$ last, or nth term;
$d =$ common difference;
$n =$ number of terms; and
$s =$ their sum.

The second term $= f + (2-1)d = f + d$; the fourth term $= f + (4-1)d$; and the nth term $=$

$$f + (n-1)d. \qquad (1)$$

From equation (1) we obtain

$$f = l \pm (n-1)d. \qquad (2) \qquad\qquad d = \frac{l-f}{n-1}. \qquad (4)$$

$$n = \frac{l-f}{d} + 1. \qquad (3) \qquad\qquad s = \frac{n}{2}(f+l). \qquad (5)$$

Substituting the value of l from (1),

$$s = \frac{n}{2}[2f + (n-1)d]. \qquad (6)$$

EXAMPLE 1.—A company contracts to put down a bore hole at one dollar ($1) per foot for the first 100 ft.; three dollars ($3) per foot for the second 100 ft.; and two dollars ($2) per foot additional for each successive 100 ft. The hole was 800 ft. deep. What was the cost?

$n = 8$; $f = 100$; and $d = 2$. Substitute these values in formula (6).

$$s = \tfrac{8}{2}[2 \times 100 + (8-1)\,200] = \$6{,}400. \quad \text{Ans.}$$

EXAMPLE 2.—If water flowing 10.12 gal. per min. be struck in a shaft 30 ft. below the surface, and the increase in flow be .02 gal. per ft. till the depth be 200 ft., and thence the flow decreases .02 gal. per ft. till the rock be dry, how deep was the shaft at the last point, and what was the total amount of water flowing into it per minute?

During the increase of flow, $n = 170$; $f = 10.12$; and $d = .02$. l [by formula (1)] $= 10.12 + (170-1).02 = 13.50$, or 13.50 gal. flow at a depth of 200 ft., and $s = \frac{170}{2}\,[2 \times 10.12 + (170-1).02] = 2{,}007.7$ gal. flowing in along the first 200 ft. in depth.

During the decrease in flow $f = 13.50$; $d = .02$, and $l = .02$.

$$n \text{ [formula (3)]} = \frac{l-f}{d} + 1, \text{ for a decreasing progression}$$

$$n = -\frac{f-l}{d} + 1.$$

Then, $-\dfrac{13.50 - .02}{.02} + 1 = 675$, the depth at which the rock will run dry, and $s = \frac{675}{2}\,[2 \times .02 + (675-1)\,.02]$, or 4,563 gal.. the amount of water that will flow in per minute along the last 675 ft. The total amount of water flowing in along the total depth of 875 ft. is 2,007.7 + 4,563, or 6,570.7 gal. Ans.

GEOMETRICAL PROGRESSION.

A series of quantities, in which each is derived from that which precedes it, by multiplication by a constant quantity, is called a *geometrical progression.* If the multiplier be a whole number, the progression is styled *increasing;* if it be a fraction, the progression is styled *decreasing.* The series

1, 2, 4, 8, 16, 32

has 2 for a multiplier, and is an increasing progression. The series

32, 16, 8, 4, 2, 1,

$1, \frac{1}{2}, \frac{1}{4}, \frac{1}{8}, \frac{1}{16}, \frac{1}{32}$

have $\frac{1}{2}$ for a multiplier, and are decreasing progressions.

The common multiplier in a geometrical progression is called the *common ratio;* or, briefly, the *ratio.*

Let
f = first term;
l = last term, whose number from f is n;
n = number of terms;
r = ratio;
s = sum of terms.

$$l = fr^{n-1}. \qquad (1) \qquad\qquad f = \frac{l}{r^{n-1}}. \qquad (4)$$

$$s = \frac{f(r^n - 1)}{r - 1}. \qquad (2) \qquad\qquad f = s - r\,(s - l). \qquad (5)$$

$$s = \frac{lr - f}{r - 1}. \qquad (3) \qquad\qquad r = \frac{s - f}{s - l}. \qquad (6)$$

EXAMPLE.—If a man should contract to sink a shaft to the base of the coal measures at the rate of $\frac{1}{16}$ cent for the first 50 ft.; $\frac{1}{8}$ cent for the second 50 ft.; $\frac{1}{4}$ cent for the third 50 ft.; and so on at the same rate, how much would be due if the shaft were 1,500 ft. deep?

$$f = \tfrac{1}{16};\ n = 30;\ \text{and } r = 2.$$

Substituting in formula (1),

$$l = \tfrac{1}{16} \times (2^{29}) = 33{,}554{,}432, \text{ and } s \text{ [formula (3)]} = \frac{33{,}554{,}432 \times 2 - \frac{1}{16}}{2 - 1}$$

$$= \$671{,}088.63\tfrac{15}{16}. \quad \text{Ans.}$$

LOGARITHMS.

USE OF LOGARITHMS.

Logarithms are designed to diminish the labor of multiplication and division, by substituting in their stead addition and subtraction. A *logarithm* is the exponent of the power to which a fixed number, called the *base*, must be raised to produce a given number. The base of the common system is 10, and, as a logarithm is the exponent of the power to which the base must be raised in order to be equal to a given number, all numbers are to be regarded as powers of 10; hence,

$10^0 = 1$, we have logarithm of $1 = 0$.
$10^1 = 10$, we have logarithm of $10 = 1$.
$10^2 = 100$, we have logarithm of $100 = 2$.
$10^3 = 1{,}000$, we have logarithm of $1{,}000 = 3$.
$10^4 = 10{,}000$, we have logarithm of $10{,}000 = 4$.

The logarithms of numbers between 1 and 10 are less than unity, and are expressed as decimals. The logarithm of any number between 10 and 100 is more than 1 and less than 2, hence it is equal to 1 plus a decimal. Between 100 and 1,000, it is equal to 2 plus a decimal, etc.

The integral part of a logarithm is its **characteristic**, the decimal part is its **mantissa**.

EXAMPLE.—The log of 67.7 is 1.83059, the characteristic of this logarithm is 1 and the mantissa is .83059.

The characteristic of a logarithm is always 1 less than the number of whole figures expressing that number, and may be either negative or positive.

The characteristic of the logarithm of 7 is 0; of 17 is 1; of 717 is 2; etc.

The mantissa is the decimal portion of a logarithm, and is always considered positive.

To Find the Logarithm of Any Number Between 1 and 100.—Look on the first page of the table, along the column marked "No.," for the given number; opposite it will be found the logarithm with its characteristic.

To Find the Logarithm of Any Number Consisting of Three Figures.—Proceed in the same manner and find the decimal in the first column to the right of the number; prefix to this the characteristic 2. Thus, the logarithm of 327 is 2.51455. As the first two figures of the decimal are the same for several successive figures, they are only given where they change. Thus, the decimal part of the logarithm of 302 is .48001. The first two figures remain the same up to 310, and are therefore to be supplied.

To Find the Logarithm of Any Number of Four Figures.—Look in the column headed "No." for the first three figures, and then along the top of the page for the fourth figure. Down the column headed by the fourth figure, and opposite the first three, will be found the decimal part. To this prefix the characteristic 3.

To Find the Logarithm of Any Number Containing More Than Four Figures. Place a decimal point after the fourth figure from the left, thus changing the number into an integer and a decimal. If the decimal part contains more than two figures, and its second figure is 5 or greater, add 1 to the first figure in the decimal. Find the mantissa of the first four figures and subtract it from the next greater mantissa in the table. Under the heading "P. P." find a column headed by the difference first found; find in this column the number opposite the number corresponding to the first figure of the decimal, or the first figure increased by one, and add it to the mantissa already found for the first four figures of the given number.

EXAMPLE.—What is the logarithm of 234,567?

Placing a decimal point after the fourth figure from the left, we have 2,345.67. The mantissa of 2,345 is .37014; the difference between .37014 and the next higher logarithm .37033 is 19. Add 1 to the first figure of the decimal 6, and in the column headed 19, under "P. P.," opposite 7, we find 13.3, which, added to the portion of the mantissa already found, .37014, gives .37027. The characteristic is 5, hence the logarithm is 5.37027.

To Find the Logarithm of a Decimal Fraction.—Proceed according to previous rules, except in regard to the characteristic. Where the number consists

of a whole number and a decimal, the characteristic is 1 less than the *whole* number. Where it is a simple decimal, or when there are no ciphers between the decimal point and the first numerator, the characteristic is negative, and is expressed by 1, with a minus sign over it. Where there is one cipher between the decimal point and first numerator, the characteristic is 2, with a minus sign over it. Where there are 2 ciphers, the characteristic is 3, with a minus sign over it. Thus:

The logarithm of 67.7 is 1.83059.
The logarithm of 6.77 is 0.83059.
The logarithm of .677 is $\bar{1}.83059$.
The logarithm of .0677 is $\bar{2}.83059$.
The logarithm of .00677 is $\bar{3}.83059$.

The characteristic only is negative. The decimal part is positive.

To Find the Logarithm of a Vulgar Fraction.—Subtract the logarithm of the denominator from the logarithm of the numerator. The difference is the logarithm of the fraction.

EXAMPLE.—Find logarithm of $\frac{4}{10}$.

$$\begin{aligned} \text{Log } 4 &= 0.60206 \\ \text{Log } 10 &= 1. \\ \hline &\quad \bar{1}.60206 \end{aligned}$$

$\bar{1}.60206$ is the logarithm of .4.

To Find the Natural Number Corresponding to Any Logarithm.—Look in the column headed "0" for the first two figures of the decimal part; the other four figures are to be looked for in the same or in one of the nine following columns. If they are exactly found, the number must be made to correspond with the characteristic by pointing off decimals or annexing ciphers.

If the decimal portion cannot be found exactly, find the next lower logarithm, subtract it from the given logarithm, divide the difference by the difference between the next lower and the next higher logarithm, and annex the quotient to the natural number found opposite the lower logarithm.

To Multiply by the Use of Logarithms.—Add the logarithms of the factors together; the sum will be the logarithm of their product.

EXAMPLE.— 67.7 × .677.

$$\begin{aligned} \text{Log } 67.7 &= 1.83059 \\ \text{Log } .677 &= \bar{1}.83059 \\ \hline &\quad 1.66118 \end{aligned}$$

1.66118 is the logarithm of 45.833.

To Divide by the Use of Logarithms.—Subtract the logarithm of the divisor from the logarithm of the dividend; the difference will be the logarithm of the quotient.

EXAMPLE.—Divide 67.7 by .0677.

$$\begin{aligned} \text{Log } 67.7 &= 1.83059 \\ \text{Log } .0677 &= \bar{2}.83059 \\ \hline &\quad 3.00000 \end{aligned}$$

3 is the logarithm of 1,000.

To Square a Number by the Use of Logarithms.—Multiply the logarithm of the number by 2. The product will be the logarithm of the square of the number.

EXAMPLE.—Square .677.

$$\begin{aligned} \text{Log } .677 &= \bar{1}.83059 \\ &\qquad\quad 2 \\ \hline &\quad \bar{1}.66118 \end{aligned}$$

$\bar{1}.66118$ is the logarithm of .45833.

To Cube a Number.—Multiply the logarithm of the number by 3. The product will be the logarithm of the cube of the number.

To Raise a Number to Any Power, as 4th, 5th, 6th, or 7th, multiply the logarithm of the number by 4, 5, 6, or 7, and the results will be the logarithms of the 4th, 5th, 6th, or 7th powers, respectively. Thus, a number can readily be raised to any power required.

To Extract the Square, Cube, Fourth, Fifth, or Any Root of a Number.—Divide the logarithm of the number by the index of the root required, and the quotient will be the logarithm of the required root.

Thus, to find the square root of 625:

$$\begin{aligned} &\text{Logarithm of } 625 = 2.79588. \\ &2.79588 \div 2 \quad\quad = 1.39794. \\ &1.39794 = \text{logarithm of } 25. \end{aligned}$$

Therefore, the square root of 625 is 25.

To Find the Cube, Fourth, or Any Root.—Proceed in the same way, using the index of the required root as a divisor.

To Divide a Logarithm Having a Negative Characteristic.—If the characteristic is evenly divisible by the divisor, divide in the usual manner and retain the negative sign for the characteristic in the quotient. But if the negative characteristic is less than, or not evenly divisible by, the divisor, add such a negative number to it as will make it evenly divisible, and prefix an equal positive number to the decimal part of the logarithm; then divide the increased negative characteristic by the divisor, to obtain the characteristic of the quotient desired. To obtain the decimal part of the quotient, divide the decimal part of the logarithm, with the positive number prefixed, in the usual manner. To this quotient prefix the negative characteristic already found, and this will be the quotient desired.

EXAMPLE 1.— $\dfrac{\bar{6}.3246846}{3} = \bar{2}.1082282.$

EXAMPLE 2.—

$$\frac{\overline{14}.3268472}{9} = (\overline{14} + \bar{4} = \overline{18}) + (4 + .3268472)\frac{\overline{18} + 4.3268472}{9} = \bar{2}.4807608.$$

EXAMPLE 3.—

$$\sqrt[5]{.677} = \frac{\log .677}{5} = \frac{\bar{1}.830589}{5};\ \frac{\bar{5}}{5} + \frac{4.830589}{5} = \bar{1}.9661178 = .9249+.$$

GEOMETRY.

PRINCIPLES OF GEOMETRY.

1. The sum of all the angles formed on one side of a straight line equals two right angles, or 180°.
2. The sum of all the angles formed around a point equals four right angles, or 360°.
3. When two straight lines intersect each other, the opposite or vertical angles are equal.
4. If two angles have their sides parallel, they are equal.
5. If two triangles have two sides, and the included angle of the one equal to two sides and the included angle of the other, they are equal in all their parts.
6. If two triangles have two angles, and the included side of the one equal to two angles and the included side of the other, they are equal in all their parts.
7. In any triangle, the greater side is opposite the greater angle, and the greater angle is opposite the greater side.
8. The sum of the lengths of any two sides of a triangle is greater than the length of the third side.
9. In an isosceles triangle, the angles opposite the equal sides are equal.
10. In any triangle, the sum of the three angles is equal to two right angles, or 180°.
11. If two angles of a triangle are given, the third may be found by subtracting their sum from two right angles, or 180°.
12. A triangle must have at least two acute angles, and can have but one obtuse or one right angle.
13. In any triangle, a perpendicular let fall from the apex to the base is shorter than either of the two other sides.

14. In any parallelogram, the opposite sides and angles are equal each to each.

15. The diagonals divide any paralellogram into two equal triangles.

16. The diagonals of a parallelogram bisect each other; that is, they divide each other into equal parts.

17. If the sides of a polygon be produced in the same direction, the sum of the exterior angles will equal four right angles.

18. The sum of the interior angles of a polygon is equal to twice as many right angles as the polygon has sides, less four right angles.

EXAMPLE.—The sum of the interior angles of a quadrilateral $= (2 \times 4) - 4 = 4$ right angles. The sum of the interior angles of a pentagon $= (2 \times 5) - 4 = 6$ right angles. The sum of the interior angles of a hexagon $= (2 \times 6) - 4 = 8$ right angles.

19. In equiangular polygons, each interior angle equals the sum divided by the number of sides.

20. The square described on the hypotenuse of a right-angled triangle is equal to the sum of the squares described on the other two sides. Thus, in a right-angled triangle whose base is 20 ft. and altitude 10 ft., the square of the hypotenuse equals the square of 20 + the square of 10, or 500. Then the hypotenuse equals the square root of 500, or 22.3607 ft.

21. Having the hypotenuse and one side of a right-angled triangle, the other side may be found by subtracting from the square of the hypotenuse the square of the other known side. The remainder will be the square of the required side.

22. Triangles that have an angle in each equal, are to each other as the product of the sides including those equal angles.

23. Similar triangles are to each other as the squares of their corresponding sides.

24. The perimeters of similar polygons are to each other as any two corresponding sides, and their areas are to each other as the squares of those sides.

25. The diameter of a circle is greater than any chord.

26. Any radius that is perpendicular to a chord, bisects the chord and the arc subtended by the chord.

27. Through three points not in the same line, a circumference may be made to pass.

DIRECTIONS.—Draw two lines connecting the three points. Erect perpendiculars from the centers of each of these two lines, and the point of intersection of the perpendiculars will be the center of the circle.

28. The circumferences of circles are to each other as their radii, and their areas are to each other as the squares of their radii.

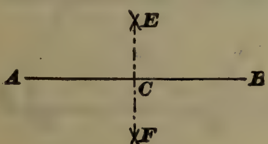
EXAMPLE 1.—If the circumference of a circle is 62.83 in. and its radius is 10 in., what is the circumference of a circle whose radius is 15 in.?

$$10 : 15 :: 62.83 : 94.245 \text{ in. Ans.}$$

EXAMPLE 2.—If a circle 6 in. in diameter has an area of 28.274 sq. in., what is the area of a circle 12 in. in diameter?

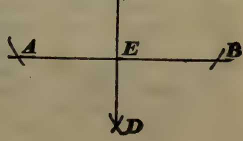
$$3^2 : 6^2 :: 28.274 : 113.096 \text{ sq. in. Ans.}$$

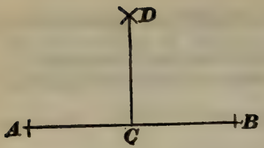
PRACTICAL PROBLEMS IN GEOMETRICAL CONSTRUCTION.



To Bisect a Given Straight Line *A B*.—From *A* and *B* as centers, with a radius greater than one-half of *A B*, describe arcs intersecting at *E* and *F*. Draw *E F*. It will bisect *A B*. *C* will be the middle point, and *E F* will be perpendicular to *A B*. The points *E* and *F* will be equidistant from *A*, *B*, or *C*.

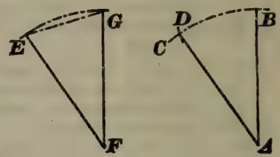
From a Given Point *C*, **Without a Straight Line** *A B*, **to Draw a Perpendicular to the Line.**—From *C* as a center, with a radius sufficiently great, describe an arc cutting *A B* in points *A* and *B*; then from *A* and *B* as centers, with a radius greater than one-half of *A B*, describe two arcs cutting each other at *D*, and draw *C D*.





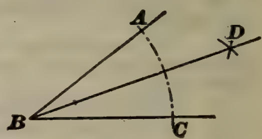
At a Given Point C in a Straight Line AB, to Erect a Perpendicular to That Line.—Take the points A and B equally distant from C, and, with A and B as centers, and a radius greater than one-half of AB, describe two arcs cutting each other at D, and draw the line DC.

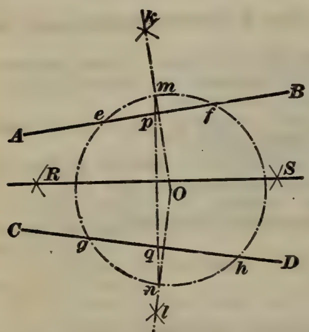
At a Point A on a Given Straight Line AB, to Make an Angle Equal to a Given Angle EFG. From F as a center, with any radius FG, describe the arc EG. From A as a center, with the same radius, describe the arc CB; then with a radius equal to the chord EG, describe an arc from B as a center, cutting CB at D, and draw AD



To Bisect a Given Arc ACB.—With the same radii and the extremities AB as centers, describe arcs intersecting at D and E. The line DE bisects the arc at C.

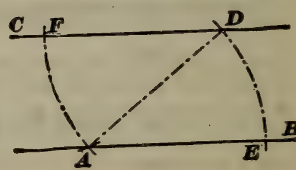
To Bisect an Angle ABC.—With any radius and B as a center, describe an arc cutting the sides at A and C. With these points as centers, describe arcs of equal radius intersecting at D. The line BD is the bisector, and the $\angle ABD = \angle DBC$.

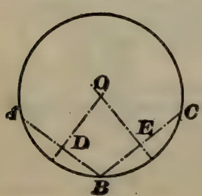




To Bisect an Open Angle (*Method by* L. L. Logan).—Let AB and CD be the sides of an open angle. With any point O as a center, describe a circle cutting the sides at e, f, g, and h, and with e and f, and g and h as centers and any radius, describe arcs intersecting at k and l, respectively. Draw Ok and Ol and mn. With p and q as centers, and any radius, describe arcs intersecting at R and S. The line drawn through RS is the required bisector.

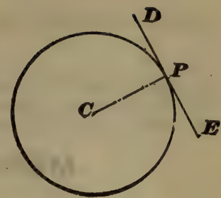
Through a Given Point A, to Draw a Straight Line Parallel to a Given Straight Line CD.—From A as a center, with a radius greater than the shortest distance from A to CD, describe an indefinite arc DE. From D as a center, with the same radius, describe the arc AF. Take DE equal to AF, and draw AB.

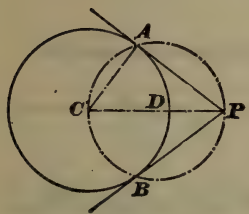




To Find the Center of a Given Circumference or Arc. Take any three points A, B, and C on the circumference, and unite them by the lines AB and BC. Bisect these chords by the perpendiculars DO and EO; their intersection is the center of the circle.

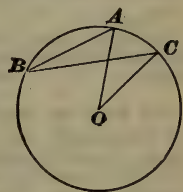
Through a Given Point P, to Draw a Tangent to a Given Circle.—1. If P be in the circumference: Find C the center of the circle, draw the radius $C\,P$, and draw $D\,E$ perpendicular to $C\,P$.

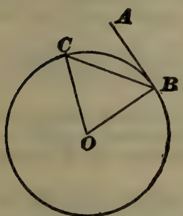




2. If P be without the circle: Join P and the center of the circle. Bisect $P\,C$ in D; with D as a center, and a radius $D\,C$, describe the circumference intersecting the given circumference at A and B. From the intersections A and B, draw $B\,P$ and $A\,P$.

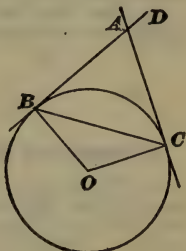
An acute angle having its vertex in the circumference and subtended by an arc is equal to one-half the central angle subtended by the same arc. Thus, the $\angle\, A\,B\,C = \frac{1}{2} \angle\, A\,O\,C$.

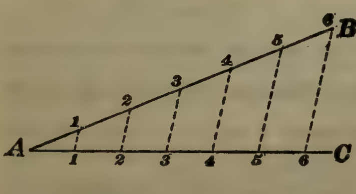




An acute angle included between a chord and a tangent is equal to one-half the central angle subtended by the chord. Thus, $\angle\, A\,B\,C = \frac{1}{2} \angle\, C\,O\,B$.

If, from a point, two tangents be drawn to a circle, they will be equal, and their angle of intersection will be equal to the central angle subtended by the chord joining the two points of tangency. Thus, $A\,B = A\,C$, and $\angle\, D\,A\,C = \angle\, B\,O\,C$.





To Divide a Straight Line Into Any Number of Equal Parts.—To divide the line $A\,B$ into, say, 6 parts, draw the line $A\,C$ from A, making any angle with $A\,B$; measure off 6 equal spaces on $A\,C$; draw $6\,B$, and from *1, 2, 3, 4, 5* on $A\,C$ draw parallels to $6\,B$. These divide $A\,B$ as required into 6 equal parts.

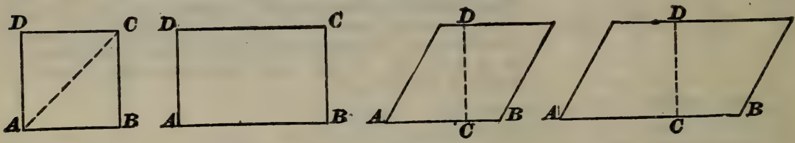
By a similar process a line may be divided into a number of unequal parts. Set off on $A\,C$ divisions proportional to the required divisions, and draw the parallel lines as explained above.

MENSURATION.

MENSURATION OF SURFACES.

PARALLELOGRAMS.

A **parallelogram** is a four-sided figure whose opposite sides are parallel.



Square. (*Four equal sides and four right angles.*)

Rectangle. (*Four right angles and opposite sides equal.*)

Rhombus. (*Four equal sides and oblique angles.*)

Rhomboid. (*Four oblique angles and opposite sides equal.*)

To Find the Area of Any Parallelogram.—Multiply the length of any side by the length of a perpendicular line from that side to the opposite one. Thus, in the foregoing figures, the areas of the square and rectangle are found by multiplying the length *A B* by the height *B C*. The areas of the rhombus and rhomboid are found by multiplying the length *A B* by the height *C D*.

To Find the Diagonal of a Square.—Multiply the length of a side by 1.41421.

Having the Diagonal, to Find the Side of a Square.—Divide the diagonal by 1.41421, or multiply it by .707107.

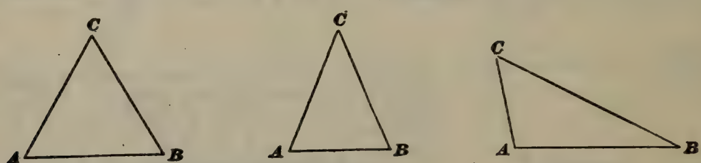
To Find a Square Equal in Area to a Given Circle.—Multiply the diameter of the circle by .886227, and the result will be the side of the required square.

To Find the Area of the Largest Square That May be Inscribed in a Circle. Square the radius of the circle, and multiply by 2.

To Find the Side of the Largest Square That May be Inscribed in a Circle. Divide the diameter of the circle by 1.41421, or multiply it by .707107.

TRIANGLES.

A **triangle** is a figure having three straight sides.



Equilateral. (*Three equal sides.*)

Isosceles. (*Two equal sides.*)

Scalene. (*Three unequal sides.*)

To Find the Area of a Triangle.—Multiply its base by one-half the perpendicular height, or altitude.

To Find the Perpendicular Height of an Equilateral Triangle.—Multiply the length of one of its sides by .866025.

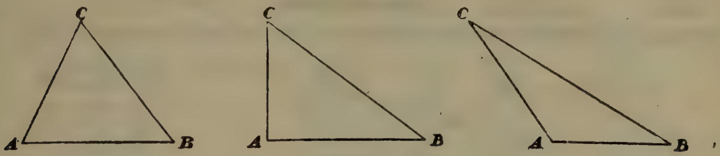
To Find the Length of Each Side of an Equilateral Triangle.—Divide the perpendicular height by .866025, or multiply the perpendicular height by 1.1547. Or, take the square root of the area and multiply it by 1.51967.

To Find the Side of a Square of Same Area as an Equilateral Triangle.—Multiply the length of one of its sides by .658037.

To Find the Diameter of a Circle of Same Area as an Equilateral Triangle. Divide the length of one of its sides by 1.34677.

The following rules apply to any triangle:

Having Two Sides and the Included Angle, to Find the Area.—Multiply together the two sides and the natural sine of the included angle, and divide the product by 2. Or, by logarithms, add together the logarithms of the two



Acute. (*Three acute angles.*) Right. (*A right angle.*) Obtuse. (*An obtuse angle.*)

sides and the logarithmic sine of the included angle, and from the sum subtract the logarithm of 2, and the result will be the logarithm of the area.

Having Three Sides of a Triangle, to Find the Area.—Add the three sides together, divide the sum by 2; from the half sum, subtract each side separately; multiply the half sum and the three remainders continuously together, and extract the square root of the product. Thus, if the triangle has three sides whose lengths are 30, 40, and 50 ft., then $\frac{30 + 40 + 50}{2} = 60$. Then, subtracting from this 60 each side separately, we have: $60 - 30 = 30$; $60 - 40 = 20$; $60 - 50 = 10$. Then, $60 \times 30 \times 20 \times 10 = 360{,}000$. The square root of $360{,}000 = 600$ sq. ft., or area.

Having the Three Sides of a Triangle, to Find Its Angles.—In the triangle ABC, let $AB = 21$ ft., $BC = 17.25$ ft., and $AC = 32$ ft. Draw BD perpendicular to AC; then,

$$32 : 21 + 17.25 = 21 - 17.25 : AD - DC;$$

or, $AD - DC = 4.48$

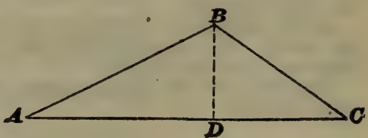
But $AD + DC = 32$

Adding, $2\,AD = 36.48$

$AD = 18.24$

Subtracting, $2\,DC = 27.52$

$DC = 13.76$



$$\cos A = \frac{18.24}{21} = .86857, \text{ or } A = 29° \, 42' \, 25.7''.$$

$$\cos C = \frac{13.76}{17.25} = .79768, \text{ or } C = 37° \, 5' \, 26.7''.$$

$B = 180° - (A + C) = 180 - (29° \, 42' \, 25.7'' + 37° \, 5' \, 26.7'') = 113° \, 12' \, 7.6''$.

Having Two Sides and Included Angle, to Find Third Side and the Other Angles. In the triangle ABC, let $AB = 19$ ft., $AC = 23$ ft., and $A = 36° \, 3' \, 29''$. Draw BD perpendicular to AC. $BD = 19 \times \sin A = 19 \times .58861 = 11.18$ ft. $AD = 19 \times \cos A = 19 \times .80842 = 15.36$ ft. $DC = 23 - 15.36 = 7.64$ ft. $\operatorname{Tan} C = \frac{11.18}{7.64} = 1.46335$, or $C = 55° \, 39' \, 10''$. $B = 180 - (A + C) = 180 - (36° \, 3' \, 29'' + 55° \, 39' \, 10'') = 88° \, 17' \, 21''$. $BC = \frac{BD}{\sin C} = \frac{11.18}{.82562} = 13.54$ ft.

Having One Side and the Two Adjacent Angles, to Find the Other Two Sides. The third angle equals 180° minus the sum of the other two angles. This third angle will be the one opposite the given side. Then the sine of the angle opposite the given side is to the given side as the sine of either of the other angles is to its opposite side. Thus, in the triangle ABC, let $A = 60°$, $B = 70°$, and the side $AB = 200$ ft. Then the angle $C = 180° - (60° + 70°) = 50°$.

Then, $\sin 50° : 200 :: \sin 60° : BC$,

and $\sin 50° : 200 :: \sin 70° : AC$.

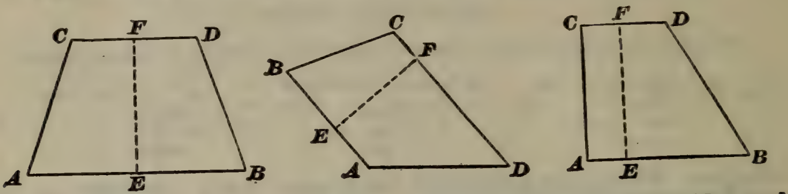
To Find the Area.—Either find the three sides as above, and follow rule already given, or multiply the natural sines of the two given angles together.

Then, as the natural sine of the single angle is to the product of the sines of the given angles, so is the square of the given side to twice the required area. Thus, $\sin C : \sin A \times \sin B :: \overline{AB}^2$: to twice the area of the triangle.

The area of any triangle is equal to half the area of a parallelogram having the same base and perpendicular height.

TRAPEZOIDS.

A **trapezoid** has four straight sides, only two of which are parallel.

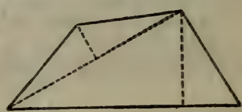


To Find the Area of a Trapezoid.—Add together the two parallel sides, and divide by 2. Multiply the quotient by the perpendicular height.

Thus, $\dfrac{AB + CD}{2} \times EF =$ area.

TRAPEZIUMS.

A **trapezium** has four sides, no two of which are parallel.



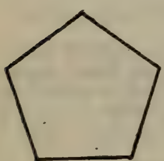
To Find the Area of a Trapezium.—Divide the trapezium into two triangles, and find the area of each according to the rules given under the head of "Triangles." Add together the areas of the two triangles, and the sum will equal the area of the trapezium. The sides and angles can be found in the same manner.

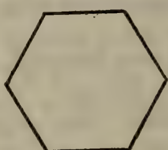
If the diagonals and the perpendiculars from them to the opposite angles are given, add together the two perpendiculars, multiply the sum by the diagonal, and divide by 2.

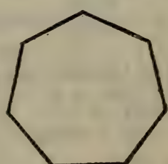
The sum of the four angles included in a trapezium always equals four right angles.

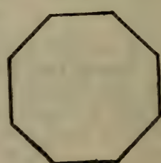
POLYGONS.

All figures bounded by more than four straight lines are called **polygons.**


Pentagon.


Hexagon.


Heptagon.


Octagon

If all the sides and angles are equal, it is a regular polygon. If not, it is an irregular polygon.

The sum of the interior angles of any polygon is equal to twice as many right angles as the polygon has sides, less four right angles.

To Find the Area of Any Regular Polygon.—Square one of its sides and multiply by the number given in the column of areas in the following table. Or, multiply the length of one of the sides by one-half the length of a perpendicular drawn to the center of the figure, and this product by the number of sides.

Having the Side of a Regular Polygon, to Find the Radius of a Circumscribing Circle.—Multiply the side by the corresponding number in following column of outer radii. If the radius of the circumscribing circle be given.

divide it by the number in column of outer radii, and the quotient will be the side of the polygon.

To Find the Area of an Irregular Polygon.—Divide it into triangles, find the

TABLE OF REGULAR POLYGONS WHOSE SIDES ARE UNITY.

Number of Sides.	Name of Polygon.	Areas.	Outer Radii.	Angles Contained Between Two Sides.	Angle at Center of Circle.
3	Equilateral triangle	.4330	.5774	60°	120°
4	Square	1.0000	.7071	90°	90°
5	Pentagon	1.7205	.8507	108°	72°
6	Hexagon	2.5981	1.0000	120°	60°
7	Heptagon	3.6339	1.1524	128° 34′ 17″+	51° 25′ 43″—
8	Octagon	4.8284	1.3066	135°	45°
9	Nonagon	6.1818	1.4619	140°	40°
10	Decagon	7.6942	1.6180	144°	36°
11	Undecagon	9.3656	1.7747	147° 16′ 22″—	32° 43′ 38″+
12	Dodecagon	11.1962	1.9319	150°	30°

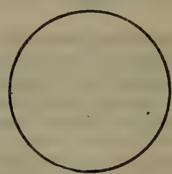
area of each triangle, and add them together. The sum will be the area of the polygon.

To Find the Area of a Figure Whose Outlines Are Very Irregular.—Draw straight lines around it that will enclose within them (as nearly as can be judged) as much space not belonging to the figure as they exclude space belonging to it. The area of the figure thus formed may be easily found by dividing into triangles.

CIRCLES.

(*See Table of Areas of Circles, Etc.*)

A circle is a figure bounded by a curved line, every point of which is equidistant from the center. Or, a circle is a regular polygon of an infinite number of sides.



The circumference of a circle equals the diameter multiplied by 3.1416, or the square root of the product of the area multiplied by 12.566.

To Find the Diameter.—Divide the circumference by 3.1416, or multiply it by .31831.

To Find the Area of a Circle.—Multiply the circumference by one-fourth of the diameter, or the square of the radius by 3.1416. Multiply the square of the diameter by .7854, or the square of the circumference by .07958.

To Find the Diameter of a Circle Equal in Area to a Given Square.—Multiply one side of the square by 1.12838.

To Find the Radius of a Circle to Circumscribe a Given Square.—Multiply one side by .7071; or take one-half the diagonal.

To Find the Side of a Square Equal in Area to a Given Circle.—Multiply the diameter by .88623.

To Find the Side of the Greatest Square in a Given Circle.—Multiply the diameter by .7071.

To Find the Area of the Greatest Square in a Given Circle.—Square the radius and multiply by 2.

To Find the Side of an Equilateral Triangle Equal in Area to a Given Circle. Multiply the diameter by 1.3468.

Having the Chord and Rise of an Arc, to Find the Radius.—Square half the chord, and divide by the rise. To the quotient add the rise, and divide by 2. Or, radius = the square of the chord of half the arc divided by twice the rise of the whole arc.

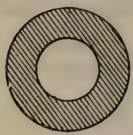
Having the Chord and Radius, to Find the Rise.—Square the radius, also square half the chord. Take the last square from the first. Extract square root of the remainder, and subtract it from the radius if the radius is greater; if not, add it to the radius.

Having the Radius and Rise, to Find the Chord.—From the radius subtract the rise (or from the rise subtract the radius, if rise is the greater), square

the remainder, and subtract it from the square of the radius. Extract the square root of the remainder, and multiply by 2.

Having the Rise of the Arc and Diameter of Circle, to Find the Chord.—Subtract the rise from the diameter, and multiply the remainder by the rise. Extract the square root of the product, and multiply by 2.

To Find the Breadth of a Circular Ring, Having Its Area and the Diameter of the Outer Circle.—Find the area of the whole circle, and from it take the area of the ring. Multiply the remainder by 1.2732, and the square root of the product will be the diameter of the inner circle. Take it from the diameter of the outer one, and the remainder will be twice the breadth.



To Find the Area of a Circular Ring.—Take the difference of the squares of the radii, and multiply it by 3.1416.

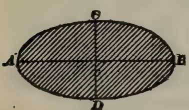
To Find the Length of an Arc When Its Degrees and Radius Are Given.—Multiply the number of degrees by .01745, and the product by the radius.

To Find the Area of a Sector.—Multiply the arc by one-half the radius. The area of the sector is to the area of the circle as the number of degrees in the sector is to 360°.

To Find the Area of a Segment.—Find the area of the sector having the same arc, and also the area of the triangle formed by the chord of the segment and the radii of the sector. If the segment is greater than a semicircle, add the two areas; if less, subtract them.

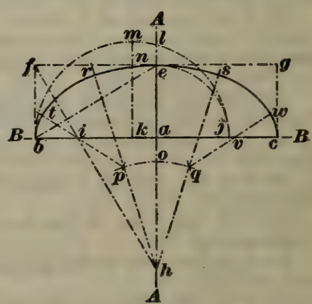
THE ELLIPSE.

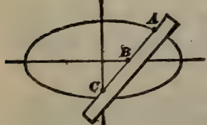
To Find the Area of an Ellipse.—Multiply one-half of the two axes AB and CD together, and multiply the product by 3.1416.



To Find the Perimeter of an Ellipse.—Multiply one-half the sum of the two axes by 3.1416.

To Draw an Approximate Ellipse (*Method by Three Squares*). Let a be the center, $b\,c$ the major, and $a\,e$ half the minor axis of an ellipse. Draw the rectangle $b\,f\,g\,c$, and the diagonal line $b\,e$; at a right angle to $b\,e$, draw line $f\,h$ cutting $B\,B$ at i. With radius $a\,e$, and from a as a center, draw the dotted arc $e\,j$, giving the point j on the line $B\,B$. From k, which is central between b and j, draw the semicircle $b\,m\,j$, cutting $A\,A$ at l. Draw the radius of the semicircle $b\,m\,j$, cutting $f\,g$ at n. With radius $m\,n$, mark on $A\,A$, at and from a as a center, the point o. With radius $h\,o$, and from center h, draw the arc $p\,o\,q$. With radius $a\,l$, and from b and c as centers, draw arcs cutting $p\,o\,q$ at the points p and q. Draw the lines $h\,p\,r$ and $h\,q\,s$, and also the lines $p\,i\,t$ and $q\,v\,w$. From h as a center, draw that part of the ellipse lying between r and s with radius $h\,r$. From p as a center draw that part of the ellipse lying between r and t with the radius $p\,r$. From q, draw the ellipse from s to w. With radius $i\,t$, from i as a center, draw the ellipse from t to b with radius $i\,t$, and from v as a center, draw the ellipse from w to c, and one-half the ellipse will be drawn. It will be seen that the whole construction has been performed to find the centers h, p, q, i, and v, and that while v and i may be used to carry the curve around the other side or half of the ellipse, new centers must be provided for h, p, and q; these new centers correspond in position to h, p, q.





Straightedge Method.—On a straightedge, lay off $A\,B$ equal to one-half the short diameter and $A\,C$ equal to one-half the long diameter. Determine points on the circumference of the ellipse by marking positions of A, as the point B is moved along the major axis and, at the same time, the point C along the minor axis.

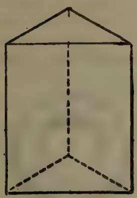
MENSURATION OF SOLIDS

THE CUBE AND THE PARALLELOPIPED

To Find the Surface of a Cube.—Multiply the area of one side by 6.

To Find the Surface of a Parallelopiped.—Add together twice the area of the base, twice the area of the side, and twice the area of the end.

To Find the Cubical Contents of a Cube or Parallelopiped.—Multiply the area of the base by the perpendicular height.



THE PRISM.

To Find the Convex Surface of a Right Prism.—Multiply the perimeter of the base by the altitude.

To find the entire surface, add the areas of the bases.

To Find the Contents of a Prism.—Multiply the area of the base by the altitude of the prism.

THE CYLINDER.

To Find the Convex Surface of a Cylinder.—Multiply the circumference of the base by the altitude.

To find the entire surface, add the areas of the ends.

To Find the Contents of a Cylinder.—Multiply the area of the base by the altitude.

THE SPHERE.

To Find the Surface of a Sphere.—Multiply the diameter by the circumference; or, square the radius and multiply it by 4 and 3.1416.

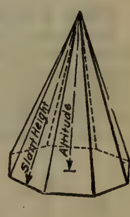
To Find the Contents of a Sphere.—Multiply the surface by one-third of the radius; or, multiply the cube of the diameter by .5236.

To Find the Surface of a Zone.—Multiply the height of the zone by the circumference of a great circle of the sphere.

To Find the Contents of a Spherical Segment of One Base. Add the square of the height to three times the square of the radius of the base; multiply this sum by the height, and the product by .5236.

The curved surface on a *hemisphere* is equal to twice its plane surface, and the curved surface on a quarter of a sphere is equal to its plane surface.

THE PYRAMID.



To Find the Convex Surface of a Pyramid.—Multiply the perimeter of the base by one-half the slant height.

To find the entire surface, add the area of the base.

To Find the Contents of a Pyramid.—Multiply the area of the base by one-third of the altitude.

THE CONE.

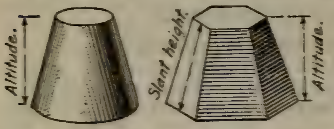
To Find the Convex Surface of a Cone.—Multiply the circumference of the base by one-half the slant height.

To find the entire surface, add the area of the base.

To Find the Contents of a Cone.—Multiply the area of the base by one-third of the altitude.

THE FRUSTUM OF A PYRAMID OR CONE.

To Find the Convex Surface.—Multiply one-half of the sum of the perimeters or circumferences of the two bases by the slant height.



The entire surface is found by adding the areas of the two bases.

To Find the Contents of a Frustum.—Add together the sum of the two bases and the square root of their product, and multiply the sum by one-third of the altitude of the frustum.

CYLINDRICAL RINGS.

A **cylindrical ring** is formed by bending a cylinder or pipe until its two ends meet.

To Find the Surface of a Cylindrical Ring.—To the thickness of the ring, add the inner diameter, multiply this sum by the thickness of the ring, and the product by 9.8696.

To Find the Contents of a Cylindrical Ring.—To the thickness of the ring add the inner diameter, multiply this sum by the square of one-half the thickness.

To Find the Volume of an Irregular Body.—Fill a vessel of known dimensions with water, and immerse the body. The contents will equal the volume of water displaced.

THE PRISMOIDAL FORMULA.

This formula is the invention of Mr. Elwood Morris, C. E., of Philadelphia, and is extensively used in calculating the cubical contents of cuttings, embankments, etc.

It embraces all parallelopipeds, prisms, pyramids, cones, wedges, etc., whether regular or irregular, right or oblique, with their frustums when cut parallel to their bases. In fact, it embraces all solids having two parallel faces or sides, provided these two faces are united by surfaces, whether plane or curved, on which, and through every point of which, a straight line may be drawn from one of the parallel faces to the other.

To Find the Contents of Any Prismoid.—Add together the areas of the two parallel surfaces, and four times the area of the section taken half way between them, and parallel to them; multiply the sum by the perpendicular distance between the two parallel sides, and divide the product by 6.

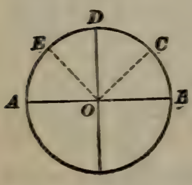
PLANE TRIGONOMETRY.

Plane trigonometry treats of the solution of plane triangles.

In every triangle, there are six parts—three sides and three angles. These parts are so related that when three of the parts are given, one being a side, the other parts may be found.

An angle is measured by the arc included between its sides, the center of the circumference being at the vertex of the angle.

For measuring angles, the circumference is divided into 360 equal parts, called **degrees**; each degree into 60 equal parts called **minutes.**



A **quadrant** is one-fourth the circumference of a circle, or 90°.

The **complement** of an arc is 90° minus the arc; DC is the complement of BC, and the angle DOC is the complement of BOC.

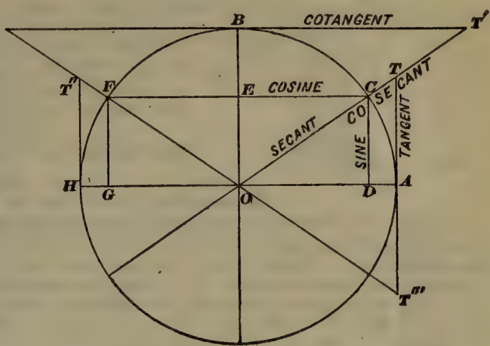
The **supplement** of an arc is 180° minus the arc; AE is the supplement of the arc BDE, and the angle BOE.

In trigonometry, instead of comparing the angles of triangles or the arcs that measure them, we compare the trigonometric functions known as the *sine*, *cosine*, *tangent*, *cotangent*, *secant*, and *cosecant*.

The **sine** of an arc is the perpendicular let fall from one extremity of the

arc on the diameter that passes through the other extremity. Thus, CD is the sine of the arc AC.

The **cosine** of an arc is the sine of its complement; or it is the distance from the foot of the sine to the center of the circle. Thus, CE or OD equals the cosine of arc AC.



The **tangent** of an arc is a line that is perpendicular to the radius at one extremity of an arc and limited by a line passing through the center of the circle and the other extremity. Thus, AT is the tangent of AC.

The **cotangent** of an arc is equal to the tangent of the complement of the arc. Thus, BT' is the cotangent of AC.

The **secant** of an arc is a line drawn from the center of the circle through one extremity of the arc, and limited by a tangent at the other extremity. Thus, OT is the secant of AC.

The **cosecant** of an arc is the secant of the complement of the arc. Thus, OT' is the cosecant of AC.

The **versed sine** of an arc is that part of the diameter included between the extremity of the arc and the foot of the sine. DA is the versed sine of AC.

The **coversed sine** is the versed sine of the complement of the arc. Thus, BE is the coversed sine of AC.

From the above definitions, we derive the following simple principles:

1. *The sine of an arc equals the sine of its supplement, and the cosine of an arc equals the cosine of its supplement.*

2. *The tangent of an arc equals the tangent of its supplement, and the cotangent of an arc equals the cotangent of its supplement.*

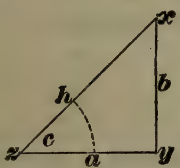
3. *The secant of an arc equals the secant of its supplement, and the cosecant equals the cosecant of its supplement.*

Thus,

sine of	$70° =$ sine of $110°$.	cosine of	$70° =$ cosine of $110°$.
tangent of	$70° =$ tangent of $110°$.	cotangent of	$70° =$ cotangent of $110°$.
secant of	$70° =$ secant of $110°$.	cosecant of	$70° =$ cosecant of $110°$.

Thus, if you want to find the sine of an angle of $120° 30'$, look for the sine of $180 - 120° 30'$, or $59° 30'$, etc.

In the rt. $\triangle\, xyz$, the following relations hold:



$$\sin c = \frac{b}{h}. \qquad \cos c = \frac{a}{h}.$$

$$\tan c = \frac{b}{a}. \qquad \cot c = \frac{a}{b}.$$

$$\sec c = \frac{h}{a}. \qquad \operatorname{cosec} c = \frac{h}{b}.$$

Functions of the sum and difference of two angles:

$$\sin (A + B) = \sin A \cos B + \cos A \sin B.$$
$$\cos (A + B) = \cos A \cos B - \sin A \sin B.$$
$$\sin (A - B) = \sin A \cos B - \cos A \sin B.$$
$$\cos (A - B) = \cos A \cos B + \sin A \sin B.$$

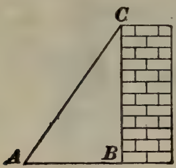
Natural sines, tangents, etc. are calculated for a circle whose radius is unity, and logarithmic sines, tangents, etc. are calculated for a circle whose radius is 10,000,000,000.

PRACTICAL EXAMPLES IN THE SOLUTION OF TRIANGLES.

CASE 1. **To Determine the Height of a Vertical Object Standing on a Horizontal Plane.**—Measure from the foot of the object any convenient horizontal

distance AB; at the point A, take the angle of elevation BAC. Then, as B is known to be a right angle, we have two angles and the included side of a triangle.

Assuming that the line AB is 300 ft. and the angle $BAC = 40°$, the angle $C = 180° - (90° + 40°) = 50°$. Then,



(1)

$$\sin C : AB :: \sin A : BC,$$

or $.766044 : 300 :: .642788 : (\ )$, or 251.73+ ft.

Or, by logarithms:

Log 300 =	2.477121
Log sin 40° =	9.808067
	12.285188
Log sin 50° =	9.884254
	2.400934 or log of 251.73+ ft.

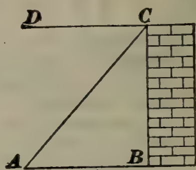
Hence, $BC = 251.73+$ ft.

CASE 2. **To Find the Distance of a Vertical Object Whose Height is Known.**—At a point A, take the angle of elevation to the top of the object. Knowing that the angle B is a right angle, we have the angles B and A and the side BC.

Assuming that the side $BC = 200$ ft. and the angle $A = 30°$, we have a triangle as follows: Angle $A = 30°$, $B = 90°$, $C = 60°$, and the side $BC = 200$ ft.

Then, $\sin A : BC :: \sin C : AB$,

or $.5 : 200 :: .866025 : (\ )$, or 346.41 ft.

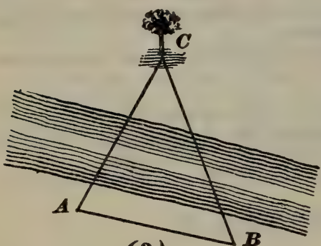


(2)

By logarithms:

Log 200 =	2.301030
Log sin 60° =	9.937531
	12.238561
Log sin 30° =	9.698970
	2.539591 or log of 346.41 ft.

CASE 3. **To Find the Distance of an Inaccessible Object.**—Measure a horizontal base line AB, and take the angles formed by the lines BAC and ABC. We then have two angles and the included side. Assuming the angle A to be 60°, the angle B 50°, and the side $AB = 500$ ft., we have the angle $C = 180° - (60° + 50°) = 70°$.



(3)

Then,

$$\sin 70° : AB :: \sin A : BC,$$

and $\sin 70° : AB :: \sin B : AC$;

or, $.939693 : 500 :: .866025 : BC$, or 460.8+,

and $.939693 : 500 :: .766044 : AC$, or 407.6+.

By logarithms:

Log 500 =	2.698970
Log sin 60° =	9.937531
	12.636501
Log sin 70° =	9.972986
	2.663515 = log of 460.8+.

Log 500 =	2.698970
Log sin 50° =	9.884254
	12.583224
Log sin 70° =	9.972986
	2.610238 = log of 407.6+.

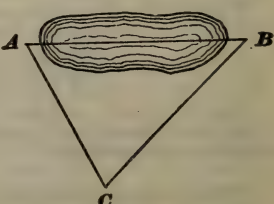
CASE 4. **To Find the Distance Between Two Objects Separated by an Impassable Barrier.**—Select any convenient station, as C, measure the lines CA and CB, and the angle included between these sides. Then we have two sides and the included angle.

Assuming the angle C to be 60°, the side CA, 600 ft., and the side CB, 500 ft., we have the following formula:

$$CA + CB : CA - CB :: \tan\frac{A+B}{2} : \tan\frac{B-A}{2}.$$

Then, $\dfrac{A+B}{2} = \dfrac{180° - 60°}{2}$, or 60°.

Then, $1{,}100 : 100 :: \tan 60° : \tan\dfrac{B-A}{2}$;



(4)

or, $1{,}100 : 100 :: 1.732050 : .157459$, or tangent of $\frac{B - A}{2}$, or $8° 57'$.

Then, $60° + 8° 57' = 68° 57'$, or angle B,
and $60° - 8° 57' = 51° 03'$, or angle A.

Having found the angles, find the third side by the same method as Case 1.

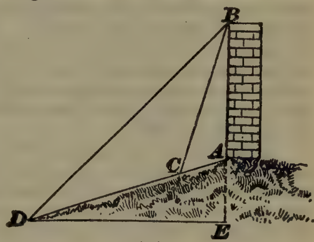
The above formula, worked out by logarithms, is as follows:

$$\begin{aligned}
\text{Log } 100 &= 2.000000\\
\text{Log tan } 60° &= 10.238561\\
&\ \overline{12.238561}\\
\text{Log } 1{,}100 &= 3.041393\\
&\ \overline{9.197168} = \text{log tan of } \frac{B-A}{2}, \text{ or } 8° 57'.
\end{aligned}$$

Then, $60° + 8° 57' = 68° 57'$, or angle B,
and $60° - 8° 57' = 51° 03'$, or angle A.

NOTE.—The greater angle is always opposite the greater side.

CASE 5. **To Find the Height of a Vertical Object Standing Upon an Inclined Plane.**—Measure any convenient distance DC on a line from the foot of the object, and, at the point D, measure the angles of elevation EDA and EDB to foot and top of tower. We then have two triangles, both of which may be solved by Case 1, and the height above D of both the foot and top will be known. The difference between them is the height of the tower.



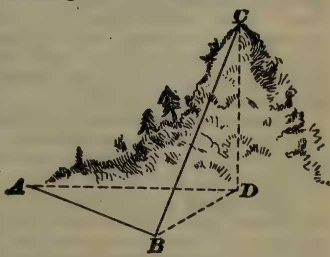
(5)

CASE 6. **To Find the Height of an Inaccessible Object Above a Horizontal Plane.** Measure any convenient horizontal line AB directly toward the object, and take the angles of elevation at A and B. We will then have sufficient data to work with. Assuming the line AB to be 1,200 ft. long, the angle A, 25°, and the angle DBC, 40°, we have the following: As the angle DBC is 40°, the angle $ABC = 90° - 40°$, or 50°.

(6)

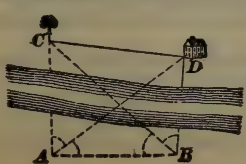
Then, having the side BC, and the angle $DBC = 40°$, and the angle $BDC = 90°$, we find the side CD by the same method as in Case 1.

Second Method.—If it is not convenient to measure a horizontal base line toward the object, measure any line AB, Fig. (6*a*), and also measure the horizontal angles BAD, ABD, and the angle of elevation DBC. Then, by means of the two triangles ABD and CBD, the height CD can be found. Then, with the line AB and the angles BAD and ABD known, we have two angles and the included side known. The third angle is readily found, and the side BD can be found. Then, in the triangle BDC, we have the angle B; by measurement, $D = 90°$, and we have the side BD. Then, the side CD, or the vertical height, can be found by Case 1.



(6 a)

CASE 7. **To Find the Distance Between Two Inaccessible Objects When Points Can Be Found From Which Both Objects Can Be Seen.**—Wishing to know the horizontal distance between a tree and a house on the opposite side of a river, measure the line AB, and, at point A, take the angles DAC, and DAB, and, at the point B, take the angles CBA and CBD.



Assume the length of $AB = 400$ ft.

Angle $DAC = 56° 30'$.
Angle $DAB = 42° 24'$.
Angle $CBA = 44° 36'$.
Angle $CBD = 68° 50'$.

In the triangle $A\,B\,D$, we have $A\,B = 400$ ft., the angle $D\,A\,B = 42°\,24'$, the angle $A\,B\,D = (44°\,36' + 68°\,50') = 113°\,26'$, and the angle $A\,D\,B = 180° - (42°\,24' + 113°\,26') = 24°\,10'$. Then, according to Case 1, find the side $D\,B$. We then have three angles and two sides of the triangle $A\,D\,B$. We find the third side $A\,D$ by Case 1.

Then in the triangle $A\,B\,C$, we have the angles $A\,B\,C$ and $B\,A\,C$, and the distance $A\,B$. From these we find the side $A\,C$. Then, in the triangle $A\,D\,C$, we have the sides $A\,D$ and $A\,C$, and the angle $D\,A\,C$, and we then find the side $C\,D$ by Case 4.

SURVEYING.

Surveying is an extension of *mensuration*, and, as ordinarily practiced, may be divided into surface work, or *ordinary surveying*, and underground work, or *mine surveying*. With slight modifications, the instruments employed in both are the same, and consist of a compass—if the work is of little importance, and accuracy is not required—a transit, level, transit and level rods, steel tape or chain, and measuring pins, and sometimes certain accessory instruments, as clinometers or slope levels, dipping needles, etc., as will be described later.

As the instrumental work is generally the same in both kinds of surveying, a description of the instruments and the usual practice on the surface will be first given, and afterwards an account of the methods of mine surveying as practiced in the anthracite regions of Pennsylvania, with the deviations from the practice of the former.

THE COMPASS.

The **compass** may be either a pocket compass, or a surveyor's compass, and may be used by holding in the hand, or with a tripod. The Jacob's staff, convenient for use on the surface, is frequently useless in the mine. The compass is not accurate enough for the construction of a general map of the mine. It is useful inasmuch as it enables the mine foreman to readily secure an *approximate* idea of the shape of the workings, and, from a plan constructed by its use, he can get an *approximate* course on which to drive an opening designed to connect two or more given points. If the opening is one that will be expensive to drive, and should be straight, the compass survey should never be relied on.

TO ADJUST THE COMPASS.

The Levels.—First bring the bubbles into the center by the pressure of the hand on different parts of the plate, and then turn the compass half way around; should the bubbles run to the ends of the tubes, it would indicate that those ends were the higher; lower them by tightening the screws immediately under, and loosening those under the lower ends until, by estimation, the error is half removed; level the plate again, and repeat the first operation until the bubbles will remain in the center during an entire revolution of the compass.

The **sights** may next be tested by observing through the slits a fine hair or thread, made exactly vertical by a plumb. Should the hair appear on one side of the slit, the sight must be adjusted by filing off its under surface on the side that seems the higher.

The **needle** is adjusted in the following manner: Having the eye nearly in the same plane with the graduated rim of the compass circle, with a small splinter of wood, or a slender iron wire, bring one end of the needle in line with any prominent division of the circle, as the zero or 90° mark, and notice if the other end corresponds with the degree on the opposite side; if it does, the needle is said to *cut* opposite degrees; if not, bend the center pin by applying a small brass wrench, furnished with most compasses, about one-eighth of an inch below the point of the pin, until the ends of the needle are brought into line with the opposite degrees.

Then, holding the needle in the same position, turn the compass half way around, and note whether it now cuts opposite degrees; if not, correct half the error by bending the needle, and the remainder by bending the center pin.

The operation must be repeated until perfect reversion is secured in the first position. This being obtained, it may be tried on another quarter of the

circle; if any error is there manifested, the correction must be made in the center pin only, the needle being already straightened by the previous operation.

When again made to cut, it should be tried on the other quarters of the circle, and corrections made in the same manner until the error is entirely removed, and the needle will reverse in every point of the divided circle.

TO USE THE COMPASS.

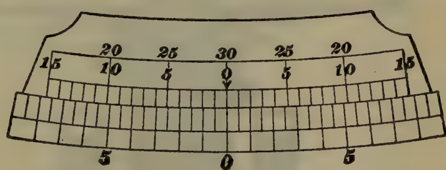
In using the compass, the surveyor should keep the south end toward his person, and read the bearings from the north end of the needle. In the surveyor's compass, he will observe that the position of the E and W letters on the face of the compass are reversed from their natural position, in order that the direction of the sight may be correctly read.

The compass circle being graduated to half degrees, a little practice will enable the surveyor to read the bearings to quarters—estimating with his eye the space bisected by the point of the needle.

The compass is usually divided into quadrants, and zero is placed at the north and south ends. 90° is placed at the E and W marks, and the graduations run right and left from the zero marks to 90°. In reading the bearing, the surveyor will notice that if the sights are pointed in a N W direction, the north end of the needle, which always points approximately north, is to the right of the front sight or front end of the telescope, and, as the number of degrees is read from it, the letters marking the cardinal points of the compass read correctly. If the E, or east, mark were on the right side of the circle, a N W course would read N E. This same remark applies to all four quadrants. The compass should always be in a level position.

MAGNETIC VARIATION.

Magnetic declination or **variation** of the needle is the angle made by the magnetic meridian with the true meridian or true north and south line. It is east or west according as the north end of the needle lies east or west of the true meridian. It is not constant, but changes from year to year, and, for this reason, in rerunning the lines of a tract of land, from field notes of some years' standing, the surveyor makes an allowance in the bearing of every line by means of a vernier that is so graduated that 30 spaces on it equal 31 on the limb of the instrument, as shown in the figure.



To Read the Vernier.—As the compass vernier is usually so made that there are but 15 spaces on each side of the zero mark, it is read as follows: Note the degrees and half degrees on the limb of the instrument. If the space passed beyond the degree or half-degree mark by the zero mark on the vernier is less than one-half the space of half a degree on the limb, the number of minutes is, of course, less than 15, and must be read from the lower row of figures. If the space passed is greater than one-half the spacing on the limb, read the upper row of figures. The line on the vernier that exactly coincides with a line on the limb is the mark that denotes the number of minutes. If the index is moved to the right, read the minutes from the left half of the vernier; if moved to the left, read the right side of the vernier.

To Turn Off the Variation.—Moving the vernier to either side, and with it, of course, the compass circle attached, set the compass to any variation by placing the instrument on some well-defined line of the old survey, and by turning the tangent screw (slow-motion screw) until the needle of the compass indicates the same bearing as that given in the old field notes of the original survey. Then screw up the clamping nut underneath the vernier and run all the other lines from the old field notes without further alteration.

The reading of the vernier on the limb gives the amount of variation since the original survey was made.

The accompanying map shows the general course and direction of isogonic lines (those passing through points where the magnetic needle has the same

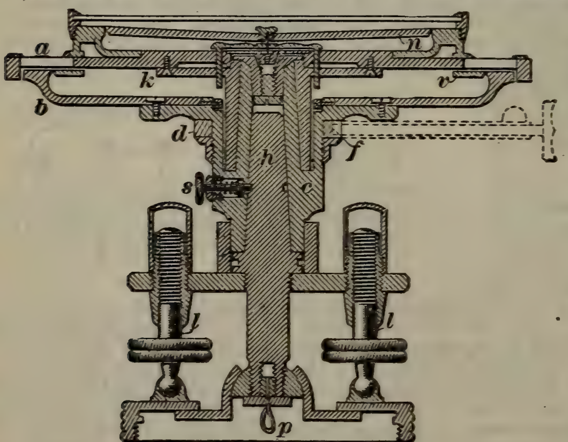
declination), in all parts of the United States and Mexico for the year 1900. These lines are drawn full when compiled from reliable records, but dotted in other places. The declination is marked in degrees at each end of every alternate line, the sign + indicating a west declination, and the sign — an east declination. The yearly variation, or change of declination, for the period 1895–1900 is marked in numerous places on the map. The annual change in declination is given in minutes; a + sign signifies increasing west or decreasing east declination, a — sign the reverse motion. Stations to the right of the agonic curve, or curve of no declination, have west declination, and those to the left, east declination. The large black circles or dots indicate the capitals of the several states.

The use of this chart is quite simple. The declination for any place within its borders is either found by inspection or by simple interpolation between the two adjacent curves; the value found is for 1900. For any other year (and fraction), a reduction for secular change between the epoch and given date must be applied. The annual change of the declination during the period 1895–1900, expressed in minutes of arc, is indicated in the chart (+ for increasing west or decreasing east declination and — for the reverse motion). The amount varies in time, but not sufficiently during a brief interval of years to cause any serious inaccuracy, and the values given on the chart can be used for a number of years to come for all practical purposes; its variation with geographical position must be estimated from the map.

THE TRANSIT.

The **transit** is the only instrument that should be used for measuring angles in any survey where great accuracy is desired. The advantages of a transit over a vernier compass are mainly due to the use of a telescope. By its use angles can be measured either vertically or horizontally, and, as the vernier is used throughout, extreme accuracy is secured.

The illustration shows the interior construction of the sockets of a transit having two verniers to the limb, the manner in which it is detached from its spindle, and how it can be taken apart when desired. The limb *b* is attached to the main socket *c*, which is carefully fitted to the conical spindle *h*, and held in place by the spring catch *s*.



The upper plate *a*, carrying the compass circle, standards, etc., is fastened to the flanges of the socket *k*, which is fitted to the upper conical surface of the main socket *c*. The weight of all the parts is supported on the small bearings of the end of the socket, as shown, so as to make as little friction as possible where such parts are being turned as a whole.

A small conical center, in which a strong screw is inserted from below, is brought down firmly on the upper end of the main socket *c*, thus holding the two plates of the instrument securely together, and, at the same time, allowing them to move freely around each other. The steel center pin on which the needle rests is held by the small disk fastened to the upper plate by two small screws above the conical center. The clamp to limb *d f*, with clamp screw, is attached to the main socket. The instrument is leveled by means of the leveling screws *l* and placed exactly over a point by means of the shifting center. The plummet is attached to the loop *p*.

The verniers on a transit differ from those on a compass in detail only.

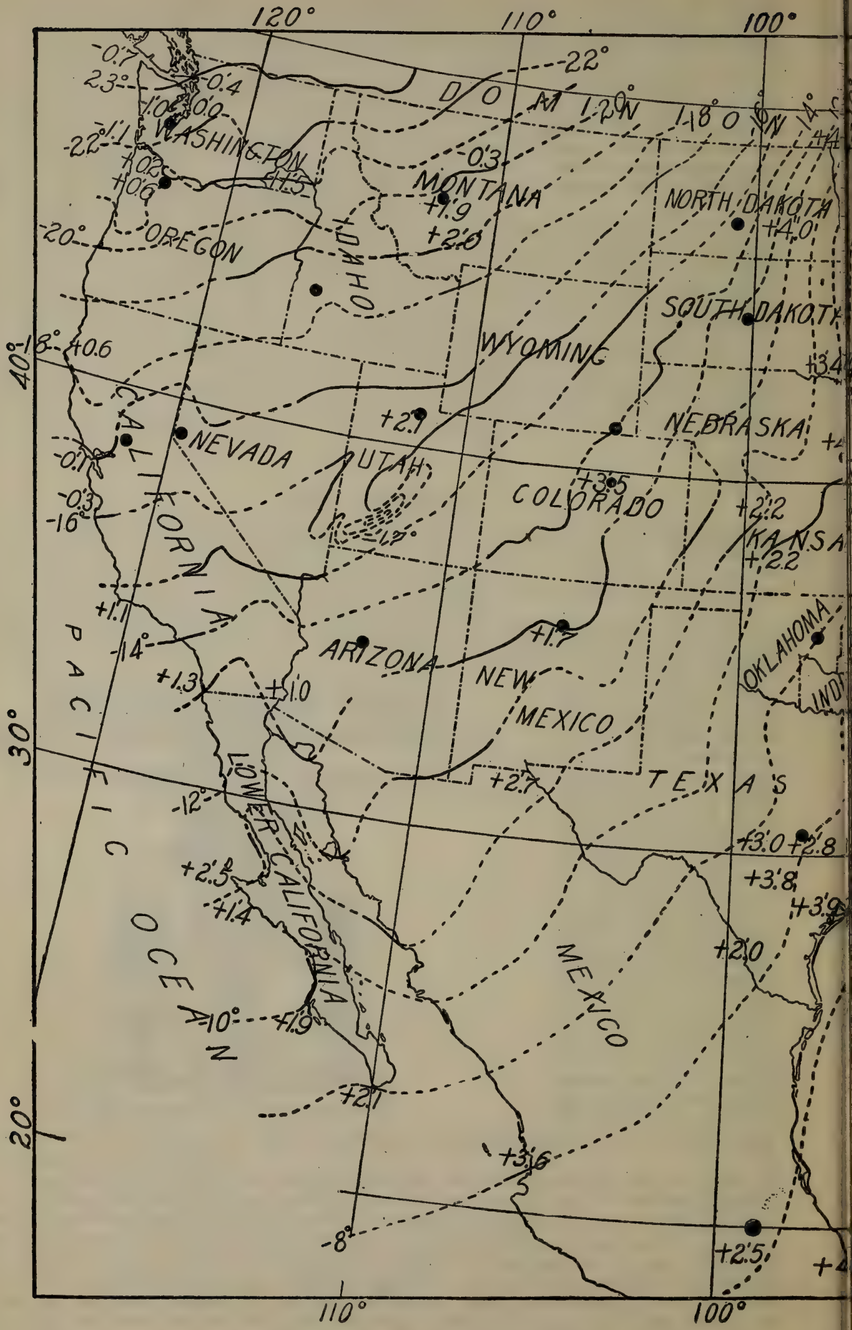
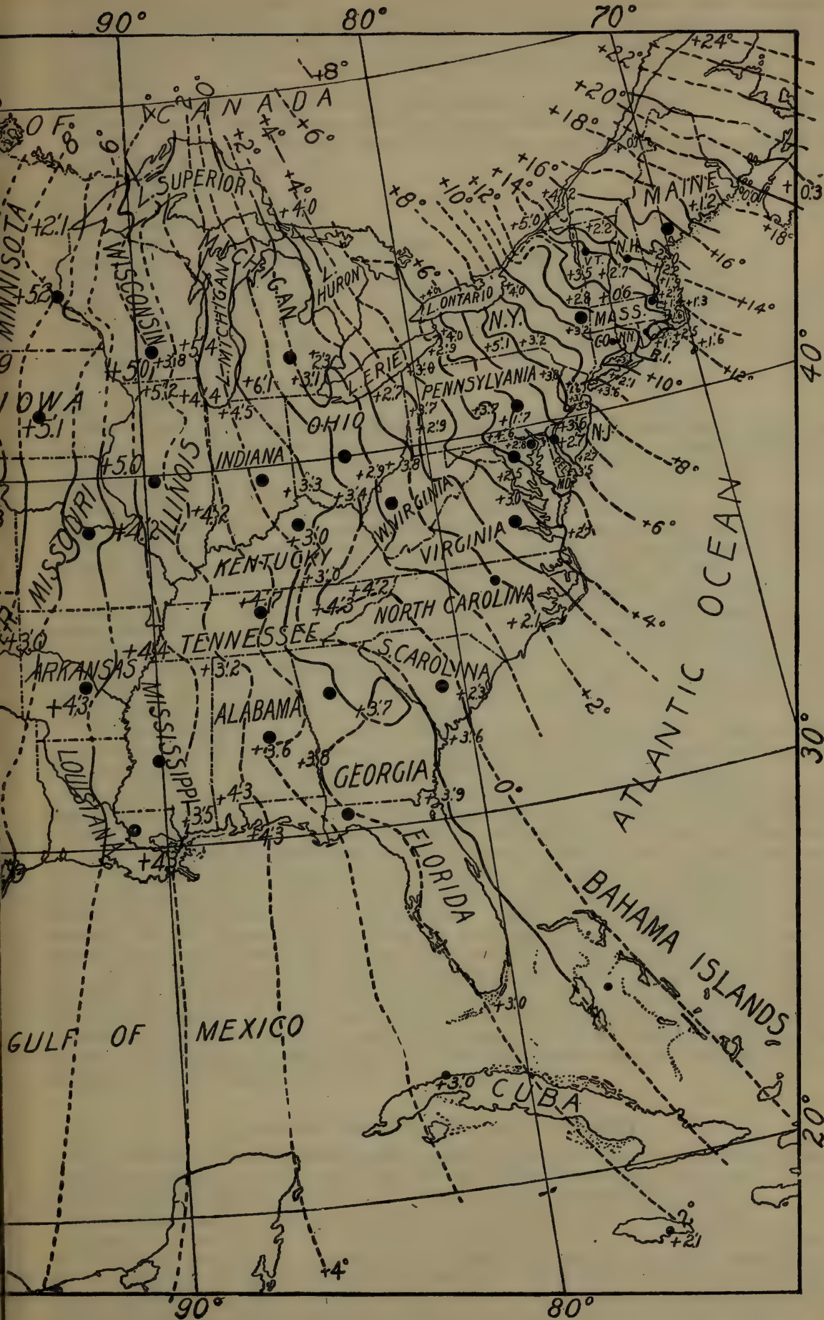


CHART SHOWING THE ISOGONIC AND AGONIC LINES IN THE UNITED STATES

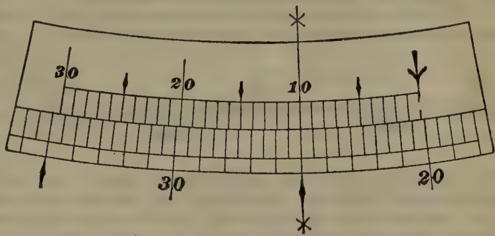


YEAR 1900, AND THE MEAN ANNUAL CHANGE FOR THE PERIOD 1885–1900.

The principle is the same. The transit vernier is so divided that 30 spaces on it equal in length 29 on the limb of the instrument. The method of reading it is practically the same as reading a compass vernier, except that of the transit the vernier is made with all of the 30 divisions on one side of the zero mark.

Each division of the vernier is therefore $\frac{1}{30}$, or, in other words, 1 minute shorter than the half-degree graduations on the limb.

In the figure the reading is 20° 10′. If the zero on the vernier should be beyond $20\frac{1}{2}$° on the limb of the transit, and the line marked 10 should coincide with a line on the limb, the reading would be 20° 40′. In case the 12th line from zero should coincide with a line on the limb, the reading would be 20° 42′, etc.



In some transits, the graduated limb has two sets of concentric graduations, the zero in both being the same, and, while the outside set is marked from 0° each way to 90°, and thence to 0° on the opposite side of the circle, the other set is marked from 0° to 360° to the right, as a clock face. The inside set has the N, S, E, and W points marked, the 0° of the inside set being taken as north.

The interior of the telescope is fitted up with a diaphragm or cross-wire ring to which cross-wires are attached. These cross-wires are either of platinum or are strands of spider web. For inside work, platinum should be used, as spider web is translucent and cannot readily be seen. They are set at right angles to each other and are so arranged that one can be adjusted so as to be vertical and the other horizontal. This diaphragm is suspended in the telescope by four capstan-headed screws, and can be moved in either direction by working the screws with an ordinary adjusting pin. The transit should not be subjected to sudden changes in temperature that may break the cross-hairs. In case of a break, remove the cross-hair diaphragm and replace the broken wire.

The intersection of the wires forms a very minute point, which, when they are adjusted, determines the optical axis of the telescope, and enables the surveyor to fix it upon an object with the greatest precision.

The imaginary line passing through the optical axis of the telescope is termed the *line of collimation*, and the operation of bringing the intersection of the wires into the optical axis is called the *adjustment of the line of collimation.*

All screws and movable parts should be covered, so as to keep out acid water or dust. If this is not done, the mine work will soon use up a transit. The vertical circle on the transit may be a full circle or a segment. The former is to be preferred, as it is always ready without intermediate clamp screws. If the dip of a sight is to be taken, the tape must be held at the transit head, and stretched in the line of sight. If the pitch of the ground is to be taken, the point of foresight must be at the same height as the axis of the transit, and the sight will then be parallel to the surface. The angle of dip is read "plus" or "minus," as it is above or below the horizontal plane. If we have the dip of a sight, and the distance between the transit head and the point of sight, we can get the vertical and horizontal components of that distance from the table of sines and cosines.

ADJUSTMENTS OF THE TRANSIT.

The use of a transit tends to disarrange some of its parts, which detracts from the accuracy of its work, but in no way injures the instrument itself. Correcting this disarrangement of parts is called *adjusting the transit.*

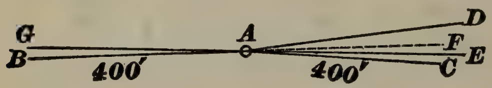
First Adjustment.—*To make the level tubes parallel to the vernier plate.*

Plant the feet of the tripod firmly in the ground. Turn the instrument until one of the levels is parallel to a pair of opposite leveling screws; the other level will be parallel to the other pair. Bring the bubble in each tube to the middle with the pair of leveling screws to which the tube is parallel. Next turn the vernier plate half way around; that is, revolve it through an angle of 180°. If the bubbles have remained in the middle of the tubes, the levels are in proper adjustment. If they have not remained so, but have

moved toward either end, bring them half way back to the middle of the tubes by means of the capstan-headed screws attached to the tubes, and the rest of the way back by the leveling screws. Again turn the vernier plate through 180°, and if the bubbles do not remain at the middle of the tubes, repeat the correction. Sometimes the adjustment is made by one trial, but usually it is necessary to repeat the operation. Each level must be adjusted separately.

Second Adjustment.—*To make the line of collimation perpendicular to the horizontal axis that supports the telescope.*

With the instrument firmly set at A, and carefully leveled, sight to a pin or tack set at a point B, about 400 ft. distant, and on level or nearly level ground. Reverse the telescope; that is, turn it over on its axis until it points in the opposite direction, and set a point at about the same distance, which will be at D.



for example, if this adjustment needs correction. Unclamp the vernier plate, and, without touching the telescope, revolve the instrument about its vertical axis sufficiently far to take another sight upon the point B. Then turn the telescope on its axis and locate a third point, as at C. Measure the distance CD, and at E, one-fourth of the distance from C to D, set the pin or tack. Move the cross-hairs, by means of the capstan-headed screws, until the vertical hair exactly covers the pin at E, being careful to move it in the opposite direction from that in which it appears it should be moved. Having done this, and then having reversed the telescope, the line of sight will not be at the point B, but at G, a distance from B equal to CE. Again sight to B, then reverse, and the pin will be at F in the same straight line with AB. It may be necessary to repeat the operation to secure an exact adjustment.

Third Adjustment.—*To make the horizontal axis of the telescope parallel to the vernier plate, so that the line of collimation will revolve in a vertical plane.*

Sight to some point A at the top of a building, so that the telescope will be elevated at a large angle. Depress the telescope, and set a pin on the ground below at a point B. Loosen the clamp, turn over the telescope, and turn the plate around sufficiently far to take an approximately accurate sight upon the point A. Then clamp the instrument and again take an exact sight to the point A. Next depress the telescope, and set another pin on the ground, which will come at C. The distance BC is double the error of adjustment. Correct the error by raising or lowering one end of the telescope axis by means of a small screw placed in the standard for that purpose. The amount the screw must be turned is determined only by repeated trials.

Fourth Adjustment.—*To make the axis of the attached level of the telescope parallel to the line of collimation.*

Drive two stakes at equal distances from the instrument and in exactly opposite directions. Level the plate carefully, and clamp the telescope in a horizontal position, or as nearly so as possible. Sight to a rod placed alternately upon each stake, and have the stakes driven down until the rod reading is the same on both stakes. When this condition is reached, the heads of the stakes are at the same level. Then move the instrument beyond one stake and set it up so that it will be in line with both stakes. Level the plate again and elevate or depress the telescope so that, when a sight is taken to the rod held on first one stake and then on the other, the reading will be alike on both. In this position, the line of collimation is level, and the bubble in the level attached to the telescope should stand in the center of the bubble tube. If it does not, bring it to the center by turning the nuts at the ends of the tube, being careful at the same time to keep the telescope in the position that gives equal rod readings on both stakes.

THE CHAIN OR STEEL TAPE AND PINS.

The **chain**, which is generally 50 or 100 ft. long, should be made of annealed steel wire, each link exactly 1 ft. in length. The links should be so made as to reduce the liability to kink to a minimum. All joints should be brazed, and handles at each end of **D** shape, or modifications of **D** shape, should be

provided. These handles should be attached to short links at each end, and the combined length of each of these short links and one handle should be exactly 1 ft. The handles should be attached to the short link in such a manner that the chain may be slightly lengthened or shortened by screwing up a nut at the handle. It should be divided every 10 ft. with a brass tag, on which either the number of points represents the number of tens from the front end, or the number of tens may be designated by figures stamped on the tags.

When a chain is purchased, one that has been warranted as "Correct, U.S. Standard," should be selected, and, before using it, it should be stretched on a level surface, care being taken that it is straight, and no kinks in it, and the extremities marked by some permanent mark. These marks can be used in the future to test the chain. It should be tested frequently, and the length kept to the standard as marked when it was new.

In chaining, the chainmen should always remember the axiom that *a straight line is the shortest distance between two points.* Ordinarily, the chain should be held horizontally, and if either end is held above the ground, a plumb-bob and line should be used to mark the end of the chain on the ground. If used on a regular incline, the chain may be stretched along the incline, and, by having the amount of declination, the horizontal and vertical distances may either be calculated or found in the Traverse Table.

For accuracy, steel tapes are now almost exclusively used by the leading mining engineers, on account of their greater accuracy as compared with chains.

The **steel tape** is simply a ribbon of steel, on which are marked, by etching, or other means, the different graduations, which may be down to inches or tenths of a foot, or may be only every foot. It is wound on a reel, and may be any desired length up to 500 ft.

A well-made tape should not vary $\frac{1}{100}$ ft. in 100 ft., at any given standard of temperature. The steel of the tape should not be too high in carbon, or it will be brittle and liable to snap on a short bend, nor should it be of too soft steel, or it will stretch when strongly pulled.

Careful gunsmiths can make and repair steel tapes with a high degree of accuracy, and fully as reasonably as the instrument makers. For outside work, tapes 1,000 ft. long have been made, but 500 ft. will be found as long as can well be used in a mine, owing to the lack of long sights, and to the increased weight of so long a tape. The average length is 300 ft. The 300 ft. are divided into 10-ft., 5-ft., 2-ft., or 1-ft. lengths, as desired, and the tenths and hundredths of a foot are read by means of a pocket tape or measuring pin. Sometimes there is an extra division before the zero mark, which is divided into feet and the first foot into tenths. With such a tape, a distance can be accurately measured to tenths, or even quite approximately to hundredths of a foot.

The ends are fitted with eyes on swivel-joints, to prevent straining by twisting. Handles of various forms have been devised to enable the tape to be stretched, or to clamp a broken end. Some parties use ordinary springs to prevent overstraining, and, in certain cases, spring scales are used, and the same degree of tension can be readily produced, and, in this way, the exact amount of sag can be calculated for any length, and the necessary correction made. To keep a mark on the tape for frequent reference, a *clip* (made by bending sharply on itself a piece of steel $\frac{1}{2}$ in. × 3 in.) is slipped upon the tape, where it will remain unless subjected to considerable force. Reels for winding the tape are made of iron or wood, and vary greatly in size and shape.

When distances do not come at even feet, the fractional part of the foot should always be noted in tenths. Thus, 53 ft. and 6 in. should always be noted as 53.5 ft.

Pins.—Pins should be from 15 to 18 in. long, made of tempered-steel wire, and should be pointed at one end, and turned with a ring for a handle. When using a 50-ft. chain, a set of pins should consist of eleven, one of which should be distinguished by some peculiar mark. This should be the last pin stuck by the front chainman. When all eleven pins have been stuck, the front chainman calls "Out!" and the back chainman comes forward and delivers him the ten pins that he has picked up, and he notes the "out." When giving the distance to the transitman, he counts his "outs," each of which consists of 500 ft., and adds to their sum the number of fifties as denoted by the pins in his possession, and the odd number of feet and fractional parts of a foot from the last pin to the front end of the chain.

The accuracy and value of a survey depend as much on the careful work of the chainmen as on anything else, and no one should be allowed to either drag or read the chain that is not intelligent enough to appreciate the importance of extreme accuracy.

Pins are generally used in outside work, where they can be easily stuck into the ground, readily seen, and avoided, and the chances of their being disturbed are slight. Inside work generally contains so many chances of error in their use that they are usually abandoned in favor of other methods. If the sight be longer than the length of the tape, it is usual to drive a tack in a sill or a collar at a point intermediate between the stations, and take a measurement to the tack from each station, with the dip of the sights; or a tripod is set up in the line of sight, and the horizontal distance is measured from each station to the string of the plumb-bob under the tripod. The first method is the more accurate.

Plumb-Bob.—The plumb-bob takes the place of the transit rod in underground work, as the stations are usually in the roof, and strings are hung from them to furnish foresights and backsights. Plumb-bobs vary in weight and shape. At various times and in various countries where mine surveys have been made, the idea of sighting at a flame has been considered, and, from rough methods of setting a lamp on the floor on foresight and backsight, there have arisen various forms of plummet lamps. The idea is to continue the practice of sighting to a flame, but to make that flame exactly under the station, and to avoid the difficulty in sighting to the string of the plummet. The idea is good, but there has never been devised a plummet lamp that would be as free from error under all circumstances as the old-fashioned plummet, so that the majority of the best engineers have gone back to the plummet. The best plummet is the one that combines the least surface with the greatest weight, and the ordinary shapes used for outside work are the best for inside also. In a "windy" place, a hole can be dug in the ballast of the track and the "bob" let into this shelter where it will be unaffected by the air. The cord is best illuminated by placing a white paper or cardboard behind it and holding the lamp in front and to one side. The string shows as a dark line against a white ground, and there is less difficulty in finding it than when the light is placed exactly behind it, and in this way a careless man cannot burn the string by poking the flame against it. The white background will also illuminate the cross-hairs of the transit. The backsight "bob" can be made of lead, as there are no "centers" to be set by this man. A number of varieties have been made for the foresight, to aid him in "center setting"; but all get out of order easily. A quick man will do as good work with the old-style bob, and have none of the accidents common to the others. In general, it may be said that the instruments used for outside work will be sufficient for mine work also.

The **clinometer, or slope level,** is a valuable instrument for side-note work; but it is not accurate enough for a survey, and its place is taken by the vertical circle on the transit. There are two styles of clinometer, with a bubble and with a pendulum. The latter is the old-fashioned and more accurate German "Gradbogen" that is found on some old corps. The bubble variety is much more easily rendered worthless by the breaking of the bubble tube, and in general is not so accurate as the other style, which consists of a semicircular protractor cut out of thin brass and furnished with hooks at each end, that it can be hung on a stretched string so that the string will pass through the 0° and 180° points. The dip is read by a pendulum swung from the center of the circle. If made sufficiently large it will readily read to quarter degrees. By inclining the string parallel to the surface and hanging the clinometer, the dip will be obtained. A pocket instrument combining a compass and clinometer can be obtained from any dealer in surveying instruments.

FIELD NOTES FOR AN OUTSIDE COMPASS SURVEY.

Call place of beginning Station 1.

Stations.	*Bearings.*	*Distances.*
1–2	N 35° E	270.0

At 1 + 37 ft. crossed small stream 3 ft. wide.
At 1 + 116 ft. = first side of road.
At 1 + 131 ft. = second side of road.
At 1 + 137 ft. = blazed and painted pine tree, 3 ft. left, marked for a "go by."

Station 2 is a stake at foot of white-oak tree, blazed and painted on four sides for corner.

2–3	N $83\frac{1}{2}$° E	129.0

Station 3 is a stake-and-stones corner.

3–4	S 57° E	222.0

3 + 64 ft. = center of small stream 2 ft. wide.
3 + 196 ft. = white oak "go by," 2 ft. right.
Station 4 = cut stone corner.

4–5	S $34\frac{1}{4}$° W	355.0

4 + 174 ft. = ledge of sandstone 10 ft. thick, dipping 27° south.

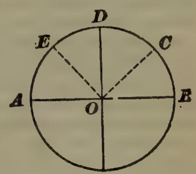
5–1	N $56\frac{1}{2}$° W	323.0

5 + 274 ft. = ledge of sandstone 10 ft. thick, dipping 25° south (evidently continuation of same ledge as at 4 + 174).
Station 1 = place of beginning.

TRANSIT SURVEYING.

To Read an Angle.—The angle read may be included or deflected. If we set up at *O* with backsight at *B* and foresight at *C*, we shall find that there are two angles made by the line *C O* with the line *B O A*, namely the included angle *B O C*, and the deflected angle *C O A*.

To Read the Included Angle.—Set the zeros of vernier and graduated limb together accurately, and clamp the plates. Turn the telescope on the backsight, with the level bubble down, and, when set, fasten lower clamp so as to fix both clamped plates to the tripod head. Loosen the upper clamp and turn the telescope to *C* and set accurately. The vernier will read, for example, "45° left angle."



To Read the Deflected Angle.—Arrange verniers as above, and be sure and turn the telescope over on its axis till the bubble tube is up, and then take the backsight and fix lower clamp. Turn the telescope back (this is called "plunging" the telescope) and sight to foresight and fix as before. The vernier will read a "right angle of 135°." The sum of included and deflected angles must always be 180°.

NOTE.—In making a survey by included angles, we must add or subtract 180° at each reading to have the vernier and compass agree; by deflected angles, they will agree without the above addition or subtraction, and the latter method is generally used.

TO MAKE A SURVEY WITH A TRANSIT.

By Individual Angles.—Set vernier at zero of limb, plunge telescope, and, when set on backsight, loosen needle and read bearing of the line from backsight to set-up. Plunge telescope back and set on foresight and read both needle and vernier. The difference in needle readings should agree with the vernier reading within 15′, as local attraction will affect the needle equally on both sights.

NOTE.—Any mass of iron or steel that may and will be moved during the readings of the needle, will affect the same and destroy the value of the needle as a check. The tape and other iron materials should not be moved during the taking of angles.

By Continuous Vernier.—Set vernier at zero, unclamp compass needle, and, when stationary, turn the north point of compass limb so as to coincide with the north point of the needle. Fix lower clamp, plunge telescope, and take backsight by loosening upper clamp. The vernier and needle should agree in giving the magnetic bearing of the line from backsight to set-up. Record this in note book; plunge telescope, and take foresight. Needle and vernier should agree as before. After making record, set up over foresight and take sight to station just left with telescope plunged, having first seen that the vernier reads exactly as it did on the last foresight, as a slip in carrying the transit from one station to another, which is not detected at the time, can never be checked afterwards when the final work is found to be in error. The foresight is taken as before. On every sight the needle and vernier should agree if there is no local attraction of the needle.

If we can see all the corners of a field that is to be surveyed from a central point, we can make the survey by setting up at that point, and, with one

corner as a backsight, take all the other corners as foresights with but one set-up, and by measuring from this point to all of the corners; or we can set up at any corner and run a line of survey around the field. This latter method is called *meandering*. Both methods will give the same result when plotted; but the former is much quicker, as the boundaries of a tract are frequently overgrown with bushes that must be cleared to allow a sight; while a central point can frequently be found that will allow a free sight to all the corners, and the distance can be measured by tape, or stadia. As the central point is nearer the corners than they are to one another, it follows that a shorter distance must be chained or cut in the case of a central set-up.

Outside surveys may be made for many purposes. It matters not what the purpose is, the work should be fully and accurately done, and the map should contain everything that will throw light upon the subject. If the outside work is to be connected with inside surveys, there are a number of points to be observed, and they will be given under the head of underground work.

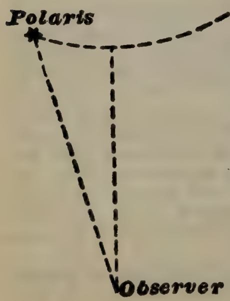
Meridians, or Base Lines.—The surveys must be based on some meridian, and started from some fixed point. There are four kinds of meridians, or "base lines."

First.—A line already on the ground, as one of the sides of the tract, is taken as a base. The subsequent work is referred to one or both ends of this line, and all angles measured are taken as deviations from it.

Second.—A stone post is sunk in the ground, or, better, an iron plug is put into rock "in place"—that is, not loose rock, even if a large boulder—at such a distance from the works as to be beyond the influence of moving machinery, and a line of sight is taken to some permanent natural object, as far distant as can be clearly seen under adverse circumstances, as cloudy or dark weather. This line of sight is the base line, and the plug is the origin. No measurements of distance are needed. If no natural objects exist, a station is set up at a distance, so as to be as permanent as possible, and angles are turned from this to other points, so as to check any movement in it. Generally there are a number of tall chimneys, church spires, etc. to be found. While this is preferable to the first, it gives no method of check in underground work, and is seldom used.

Third.—The magnetic meridian is taken as the base line. The transit is set up over a plug, as just noted, and the subsequent work is as described under running continuous vernier. As the needle is subject to constant variation, this base line will afford a check underground only for a short time after the meridian is established, and all subsequent work can be checked only by applying the difference between the variation at the time of establishment, and at the time of making the survey. If the time of establishing the survey should be lost, the base line would become no better than that noted in Case 2.

Fourth.—The true meridian is taken as a base. The true north and south line may be determined by observing the North Star, Polaris, or by observing the sun. The North Star does not lie exactly at the North Pole, but revolves about it in a small circle. There are two times in a day when it is exactly above or below the pole, and we take our sight at one of these times, when our transits do not have their graduated limbs made accurately enough to apply the proper angle for a sight at any other time. If we do not know the time when the star is crossing the meridian, we can find it by remembering that the third star in the handle of the "dipper" is in the same vertical plane with the north star 17 minutes before the latter crosses the meridian.

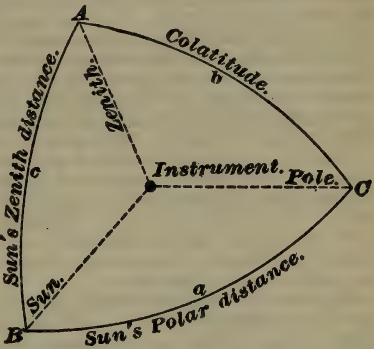


The true meridian will give us an invariable base line. At any date after the establishment of the same, we can check the work above or below ground by applying the variation of the needle.

To Find the True North by an Observation of the North Star, Polaris, at Elongation.—This star has a motion around a small circle, the azimuth angle of which from the north is known for different latitudes. The star may be readily found by following the line of the so-called pointers in the *Big Bear*, or *Dipper*. The time of the greatest eastern or western elongation is found from a table. Some 10 minutes before this time the transit is carefully set up and leveled over a peg. The cross-wires are made to bisect the star; they are

illuminated by a light held under the reflector fastened on the object end of the telescope. The star is followed with the cross-wires until its motion toward the point of its greatest elongation ceases. The telescope is lowered vertically, care being taken, of course, not to move it horizontally, and a peg is set up on the line, say 300 ft. or 400 ft. distant. The next morning the correction is made for the star's azimuth. These corrections are different for different latitudes and different years. They are to be found in the nautical almanac.

The method "by equal shadows" may be used with considerable accuracy, if we take a sufficiently long staff, or can obtain the shadows of a tall spire on a level surface. A vertical staff casts equal shadows at the same time before and after noon. If we drive a stake at any time before noon, in the extremity of the shadow cast by such a staff, and measure its distance from the staff, we have one leg of an angle. After noon we wait till the shadow becomes exactly as long as the distance measured, and drive a stake at the extremity of the shadow. A line bisecting the angle made by lines drawn from these two stakes to the staff will be in the meridian.



Establishing a Meridian Line With the Solar Attachment.—The angle from the equator to the horizon of a place is its *latitude;* consequently, from the zenith to the pole is the *colatitude,* or 90° — latitude. The angular distance from the equator to the sun is the *declination;* consequently, from the sun to the pole is the *polar distance.* The angular distance from the horizon to the sun is the sun's *altitude;* consequently, the *zenith distance* is the angular distance between the sun and the zenith.

Adjustments of Burt's Solar Attachment.—After the instrument has been carefully leveled, the zero of the vernier of the solar is placed opposite the zero of the arc. The horizontal plates of the instrument are clamped, and the sun's image brought between the horizontal lines of either silver plate by any manipulation of the instrument and attachment possible, keeping the plates horizontal and the zero of the vernier opposite the zero on the arc. When the image is accurately between the horizontal lines, the arc is revolved so that the image falls on the other plate; this must be done rapidly, as the sun's image moves. If it does not fall between the lines, half the error is corrected by the tangent screw of the solar and half by the tangent screw of the telescope. The operation is repeated until the sun's image falls between the lines of the second plate, after a revolution of the arc, it having been made to fall between the lines of the first, as described. Near noon is a good time to make this adjustment, as the sun's apparent motion is not so rapid. The zero of the vernier is now brought opposite to the zero of the arc by loosening the screws that fasten the vernier, and sliding it as may be necessary. It is often difficult to make the zeros come exactly opposite each other, as the vernier plate is apt to move slightly when the screws are tightened again. The second adjustment is to make the tops of the rectangular blocks of the solar attachment level, when the telescope is level and the arc of the solar is set at zero. Level the transit carefully, as before described, set the solar at zero and place the level, furnished with the solar, across the tops of the blocks. If the bubble comes to the center of the tube, no correction is needed; if it does not, correct the error by turning the screws under the hour circle, care being taken in this as in all other movements of these adjusting screws, to leave them tight after the correction. Revolve 180° and correct again if necessary. Placing the blocks 90° horizontally from their first position, go through the same operation as described until in all positions the bubble remains centered.

To Use the Solar.—Before this instrument can be used at any given place, it is necessary to set off upon its arcs both the declination of the sun, as affected by its refraction for the given day and hour, and the latitude of the place where the observation is made.

The declination of the sun as given in the ephemeris of the nautical almanac from year to year, is calculated for apparent noon at Greenwich, England. To determine it for any other hour at a place in the United States, reference must be had, not only to the difference of time arising from the difference of longitude, but also to the change of declination during that time.

The longitude of the place, and therefore its difference in time, if not given directly in the tables of the almanac, can be ascertained very nearly by reference to that of other places given which are situated on, or very nearly on, the same meridian.

It is the practice of surveyors in states east of the Mississippi to allow a difference of 6 hours for the difference in longitude, calling the declination given in the almanac for 12 M. that of 6 A.M. at the place of observation. Beyond the meridian of Santa Fé, the allowance would be about 7 hours; and in California, Oregon, and Washington, about 8 hours. Having thus the difference of time, we very readily obtain the declination for a certain hour in the morning, which would be earlier or later as the longitude was greater or less, and the same as that of apparent noon at Greenwich on the given day. Thus, suppose the observation made at a place 5 hours later than Greenwich, then the declination given in the almanac for the given day at noon, affected by the refraction, would be the declination at the place of observation for 7 A.M. This give us the starting point.

To obtain the declination for the other hours of the day, take from the almanac the declination for apparent noon of the given day, and, as the declination is increasing or decreasing, add to, or subtract from, the declination of the first hour the difference of one hour as given in the ephemeris, that will give, when affected by the refraction, the declination of the succeeding hour. Proceed in like manner to make a table of the declinations for every hour of the day.

To Find the True North With the Burt Solar.—Find from an ephemeris or nautical almanac the sun declination for noon of the day of observation at Greenwich. Find the declination for the hour of observation at the place of observation by first figuring what time it is at the place of observation when it is noon at Greenwich. If the place of observation is west of Greenwich, it will be earlier there; if east, later, and in either case the difference will be one hour for every 15° of longitude. If the place is west, subtract the hour just found as described from the hour of the observation, and multiply the hourly difference, also taken from the ephemeris, by the remainder. If the declination is increasing from the equator either north or south, add this product to it; if decreasing, subtract it. A table of refractions is given in the ephemeris for the different latitudes and the different hours of the day. This refraction is to be added if the declination is north, and subtracted if the declination is south. Having thus ascertained the declination, lay it off on the declination arc. Set the colatitude of the place off on the vertical arc after having leveled the instrument carefully with clamped horizontal plates at zero. Always in solar observations it is well to level by means of the upper telescope bubble. Now, revolve the horizontal plates still clamped, and also the declination arc, around its polar axis until the sun's image is exactly between the horizontal lines of the silver plates. When the sun's image is between these lines, the object end of the telescope will be pointing north.

To Take the Latitude With Burt's Solar.—A few minutes before apparent noon clamp the plates at zero, level the instrument carefully, and set the zero of the vernier opposite the zero of the vertical arc. Lay off the declination, corrected for noon at the place of observation and for refraction, on the declination arc, and set the time mark on the declination arc opposite XII on the hour dial. Bring the sun's image between the horizontal lines of the silver plate by moving the plates horizontally and the telescope vertically, clamp both plates and telescope and follow with the tangent movements the rising sun. Be careful to stop when the sun ceases to mount. For a moment before apparent noon there is no perceptible motion of the image. The reading on the vertical arc is the colatitude of the place.

The colatitude should never be taken this way for direct-sight calculations, for while it satisfies the automatic solution of the true north, it may not be accurate, and the latitude needed for direct-sight calculation should be true to within a minute. With the Burt solar there is at times what is called a false image to guard against, an image that comes between the lines of the silver plates when the object end of the telescope is not pointing

north. If the time be observed on the hour dial, or the magnetic north be noticed, no error need ever occur on this score, for with the false image the time will be out considerably and also the magnetic variation.

General Remarks.—With the base line located and the survey made, we see, by coming back to the point from which we started or "closing" the work, whether it be correct in distance or angle. If it be in error, see if the error can be located (as will be shown under plotting), and if it can be found, run those parts over again; if not, repeat the whole survey. Shoving the work, as it is called, or "doctoring" it so that it will close, is the poorest practice that an engineer can engage in, as all subsequent work that depends on a doctored survey must be doctored to fit the faulty work—even if it be right in itself. Every engineer should be able to swear—not that he "thinks the survey is accurate," but "that he knows it to be so," if he should be called as a witness in court. One of the causes of inaccuracy is haste.

To make a complete map, the engineer should first make a survey around the tract to be worked, locating all the prominent physical features and improvements. If he can do so, he should make a topographical map of the tract at once; but, if time is limited, by running the vertical as well as the horizontal angle, he can carry the tidal elevation or the elevation above some assumed datum, to every station, and *mark it on the map at that point.* Then as he makes subsequent surveys, he can gradually get data enough to make a fairly complete topographical map in course of time. Every ledge of rock in place should be located, and the amount and direction of its dip, as well as the character of the rock, should be marked neatly on the map. The streams of water on the tract should be regarded as of primary importance, and should be located with exactness.

With a true meridian base line we can connect maps made at different places with little trouble. This is especially useful with adjoining mines connected at but one point. Having made the survey and come home, we must examine all the apparatus and see if the instruments are out of adjustment, as such a fact will prevent our bothering over work that will not close. It will assure us, also, that we can start out at a moment's notice with no thought of the adjustment of our tools. A famous wit said that the proper time to strop a razor was just after you had used it, as you then knew how much it needed it. The same will apply to surveying instruments and tools—especially for underground work. Here the lamp smoke, powder gases, mine dust, paint smears, acid water from "droppers," and the other abominations incident to underground surveying, especially in a coal mine, will so cover the tools that they would be useless if left uncleaned half a dozen times. As soon as the corps comes back from the mine, and before the clothes are changed, the tape must be stretched, tested, wiped, and oiled. It can be inspected to see if marks are too much worn, or it stands in need of mending, the marking pot is cleared of "muck," and fresh white paint is mixed, if the corps is going out in 24 hours; the plummets will have their strings overhauled and freed from knots; hatchets will be sharpened, and axes ground, pouches overhauled, and a supply of tacks or "spads" taken. Then the transitman changes his clothes and sets up the transit, wipes it with a cloth wet with alcohol, so as to remove dirt, oil, and paint. If water has gotten between the graduated limb and compass box, the verniers must be uncovered and the whole wiped dry. If the sulphureted hydrogen from the powder smoke has tarnished the silver surfaces of any of the graduated circles, it must be removed with whiting. Alcohol should be always used instead of water, as it will quickly evaporate and leave the parts dry. The telescope glasses are then wiped with soft chamois leather, and the instrument is tested for want of adjustment before putting it away in its box. When going to and from work, the transit should not be carried on the transit head, or the spindle will become sprung. Nor should it be carried with the arm crooked under the telescope, as the weight comes on the axis, and that soon gets sprung so that all the adjusting in the world will not make it work right. When carried in the hand, it should be reversed and the hand slipped under the compass plate and brought over so as to clamp both plates. In this way there will be no strain on any part. In case of a "fall" in the mine, remember that the transit is the baby to be protected, and stand a few bumps to save a strained or broken instrument, that will end the work for some time.

Plotting.—A "plot" is not only a piece of ground with bodies of water, roads, vegetation, etc. upon it, but refers also to the map of the same drawn to a given scale, and showing all of the above natural features. *Plotting* is

the making of such a map from notes of a survey, and may or may not require the permanent placing of the stations on the map, by which the survey is made. In underground work, the exact location and the retention of those stations is a matter of the first importance, and is secondary only to the exact plotting of the side notes. The scale of the plot is generally as large as will show the points of interest in the property; but in Pennsylvania, the maps for coal mines must be drawn to a scale of 100 ft. to an inch. There are two methods of plotting: by protractor, and by coordinates. When the scale is sufficiently large, it is a matter of little choice which method is used, if the work be carefully done with exact instruments; but with small scales—100 ft. or above, to the inch—we should use the method by coordinates. With the latter scale, the prick of a pin on the paper will represent a foot square, or a circle slightly larger than a foot in diameter. If the next station is to be located from the pin prick of the first, and that is exactly located, we may not hit the exact center of that small indentation. In fact, the chances are greatly against our doing so, and the location of the second station will probably be in error. If we have a bad habit of placing the protractor or the straightedge against one side of the pin pricks, or pencil marks, when the scale is large, we shall constantly be introducing a "personal error," as it is called, and the sum of all the errors made at each of 100 stations will bring our final point very much out of the way. On this account, and from the fact that no protractor that is movable can be used without the chances of slipping while the angle is read or marked, has led all careful engineers to abandon its use in favor of the method by coordinates. When the scale is from 1 to 25 ft. to an inch, the errors are small enough to make little chances of variation in a close of ten or twelve stations; when the survey is of short sights from a main line to points where no further work is to be done, the protractor will afford a quick method of plotting.

There is a chance of error in both methods that must be noted here, where the survey is not completed at one time. If the map be made in a day or two, and will never be extended by subsequent work, there will be no chance of error from a change in the paper on which it is made, due to moisture or dryness; but if the map be made on a series of very damp days, or a series of very dry ones, a change in the weather to the other extreme will swell or shrink the map. The general tendency in a large mine map that is frequently used, and is rolled and unrolled every day for five or six years, is to stretching, so that there will be a variation of from 1 to 5 ft. in 1,000. If we extend a recent survey on such a map, we are plotting it to a different scale to that assumed by the map under the conditions above noted. The paper on which the map is to be drawn should be tacked down to the table or board, and should be covered with squares each exactly 10 in. square. The sides of these squares should be the meridians, or north or south lines, and the tops and bottoms should run due east and west. Mark the first station on the paper, set your parallel ruler or T square on the meridian nearest it, and with the protractor produce the course to the next station. Measure the distance with a scale, and proceed in this manner to plot all the courses, using each time the meridian nearest the station the course is taken from. After all the stations have been plotted, fill in the side notes, marking everything on the map with great care and neatness. Always use the horizontal distances. All surveys should be traversed, and all plotting should be either checked by the traversing, or the principal stations should be plotted by use of the traverse. For a large mine map that will be in use many years, muslin-backed egg-shell paper must be used. It comes in a long roll, and any reasonable length, and a width up to 6 ft. can be obtained.

To Calculate the Vertical Distances.—When making the survey, read the vertical angles to all stations. If the angle is one of depression, note it with a minus sign (—) preceding it. If it is an angle of elevation, precede it with a plus sign (+). These will show whether the vertical distance is to be added to, or subtracted from, the height of the preceding station.

Having the horizontal distance and the vertical angle:
Distance × tangent of vertical angle = vertical distance.
Having the pitch distance and vertical angle:
Distance × sine of vertical angle = vertical distance.

To Calculate the Horizontal Distance, or Latitude.—Pitch distance × cosine of vertical angle = horizontal distance.
Vertical height, or departure ÷ tang. of vertical angle = horizontal distance.

To Calculate the Pitch Distance.—Horizontal distance ÷ cosine of bearing, or multiplied by secant of bearing = pitch distance.

Vertical distance ÷ sine of vertical angle, or multiplied by cosecant of bearing = pitch distance.

To Calculate the Vertical Angle.—The horizontal distance ÷ the pitch distance = cosine of vertical angle.

Vertical distance ÷ pitch distance = sine of vertical angle.

Vertical distance ÷ horizontal distance = tangent of vertical angle.

NOTE.—Whenever sines, cosines, tangents, etc. are here named, they mean the natural sines, etc. of the angle.

Plotting by Coordinates.—In describing the establishment of a meridian and a fixed point, we made the latter a stone post, or iron plug sunk in solid rock. This point is called the *origin of coordinates.* We have the principal meridian passing through this point in an exact north and south direction, and a secondary meridian or base line passing through this point at right angles to the first, or in an exact east and west line. Any point we may select on the map will be a certain distance north or south, and east or west of the origin. The lines drawn from this point at right angles to the two base lines just given are called the *coordinates of that point*, and we can plot the point when they are given. For example, the coordinates of Station 24 are North 345.67, and East 890.12. We measure 890.12 ft. east of the origin on the secondary meridian and, from this point, measure 345.67 ft. north to the point desired; or we can measure first on the primary meridian to the north and then turn off a right angle to the east and reach the same point. In any event we plot the position of each station independently of all the others, and any error in locating one is not carried to the next. When two stations are plotted, the distance between them on the map should be exactly what we found for their horizontal distance on the ground. This check shows whether our plotting is correct. This is also called *traversing* a survey if the meridian be north and south, and in books on surveying there are printed *traverse tables*, which are accurate within certain limits, but not so accurate as the *tables of coordinates* published separately, as the latter are carried to a greater number of decimals. Gurdon's Traverse Tables will enable you to find, without calculation, the coordinates for a distance of 12 miles with a chance of error of only half an inch, which is much more accurate than the graduation of the instruments with which the work was done.

With a north and south meridian, the point from which we begin to measure angles—the zero point—is the north point, and the angles are read for continuous vernier in the direction of the hands of a watch. The sines of angles are eastings and westings, and the cosines are northings and southings.

To Traverse a Survey.—To traverse a survey, means to determine by calculation how far north or south and east or west any station may be from another, the location of which is fixed. To do this, all distances must be either measured horizontally, or calculated to horizontal distances. The horizontal angles, or courses, must be either read as quadrant courses, or reduced from azimuth to quadrant courses. An azimuth course is one that is read on the transit which is graduated from 0° to 360°. A quadrant course is one read in the quadrant of the circle, as S 67° W, N 43° E, etc.

Latitude means distance north or south, and is determined by the first initial of the recorded course. Thus, if a course is S 67° W, the latitude is south; if N 43° E, the latitude is north.

Departure means distance east or west, and is determined by the last initial of the recorded course. Thus, if a course is S 67° W, the departure is west; if N 43° E, the departure is east.

The latitude = distance × cosine of bearing.

The departure = distance × sine of bearing.

If the survey is a continuous one around a tract, and ending at the place of beginning, the sum of the northings should equal the sum of the southings, and the sum of the eastings should equal the sum of the westings. Or, in other words, the sum of all the latitudes north, should equal the sum of all the latitudes south; and the sum of all the departures east, should equal the sum of all the departures west. It is evident that by coming back to the place of beginning the surveyor has traveled the same distance north as he has south, and the same distance east as he has west.

The most accurate way to construct a map is to traverse the survey and place all stations on it by the traversed distances, or to at least put a number of the principal stations on the map by the traversed distances, and

use the protractor to plot only the intermediate stations. As the origin of the survey is at the fixed point just mentioned, we must make a rough pencil sketch to find the approximate location of this point from the boundaries of the property, and the general trend of the property itself. This will show us the place to put the origin upon the paper so that all of the property can be placed on the map, and leave about the same amount of margin on all sides. It will also show us the direction the north and south line must take on the paper. When this is settled, mark the origin by a needle point, and lay the straightedge across it in the direction to be taken by the principal meridian, and draw the meridian with a quite hard pencil brought to a very fine point. Then lay off on both sides of the origin distances of 5 in., and mark them with needle points. These must be so accurately located that there will not be an error of one hundredth of an inch in them, or one foot in five hundred. At the point where we can get the longest line on the paper at right angles to the principal meridian, lay off points for a right angle accurately on each side of the meridian, and draw through the three points, by means of the straightedge, a line parallel to the secondary meridian and divide this accurately into 5″ distances as before. Through each of the points thus marked, draw lines at right angles to the lines already drawn, until the paper is accurately divided into squares 5 in. on a side, and none of them with an error of one five-hundredth. Beginning with the origin, mark the extremities of the lines passing through it zero. All distances to the east or upon the right side of the north and south zero line are marked + with respect to that line; those to the left are marked −. All distances above the east and west zero line are marked + with respect to that line, and all distances below it −. If the coordinates of a point are N 234, and E 2.468.78, we need not measure the whole east distance from the origin, but start from the north and south line marked + 20. With 5″ squares, a 6″ scale will be sufficiently long for plotting. To illustrate plotting by use of the traversed distances, we will use the following example:

Stations.	Quadrant Courses.	Distances.	Latitudes.		Departures.		Totals.			
			N	S	E	W	N	S	E	W
1–2	N 35° E	270	221		155		221		155	
2–3	N 83° 30′ E	129	15		128		236		283	
3–4	S 57° E	222		121	186		115		469	
4–5	S 34° 15′ W	355		293		200		178	269	
			236	414	469	200				

The foregoing table, calculated according to formula for latitudes and departures, shows that Station 2 is 221 ft. north and 155 ft. east of Station 1; and that Station 5 is 178 ft. south and 269 ft. east of Station 1.

These stations, or Stations 3 and 4, or all, may be placed on the map by simply making the two measurements for each station.

To Find the Area of a Tract of Land.—If a regular polygon, find the area by the rule given under the head of "Mensuration" for polygons of the same number of sides. If an irregular polygon, divide it into triangles and calculate the area of each triangle; the sum of these areas will be the area of the tract. If the tract is an irregular polygon in shape, the map should be made on as large a scale as possible, and the distances should be measured with the greatest care, owing to liability to error through very slight inaccuracies of measurement.

To Find the Contents of a Seam of Coal Under a Tract.—If the seam lies flat, multiply the area of the tract in square feet by the thickness of the seam in feet. The product will be the cubical contents of the seam in feet. If the seam is an inclined one, find its area by measuring the width of the tract on its line of pitch, and find the distance on the pitch of the seam by dividing the horizontal distance measured by the cosine of the angle of inclination. This will give you the pitch distance. Multiply the pitch distance by the length of the tract, and you will have the area of the seam. This multiplied by its thickness will give the contents.

$$\text{Tons of coal} = \frac{\text{cubic contents in feet} \times \text{Sp. Gr.} \times 62.5}{2,240}$$

LEVELING.

Instruments.—But two instruments are used—the level and a leveling rod. The level consists of a telescope to which is fitted, on the under side, a long level tube. The telescope rests in a Y at each end of a revolving bar, which is attached to a tripod head very similar to that used for a transit. The telescope is similar to the telescope of a transit. The leveling rod is merely a straight bar of wood, 6 ft. or more in length, divided into feet and tenths of a foot. A target divided into four equal parts by two lines, one parallel with the staff, and the other at right angles to it, and painted red and white, so as to make it prominent at a distance, slides on the rod and is provided with a clamp screw. The center of the target is cut out and a vernier, graduated decimally, is set in, which enables the rodman to read as close as $\frac{1}{1000}$ of a foot.

If a long rod is required, it is made of two sliding bars, which, when closed, are similar to a single rod, as described above. When used at points where it is necessary to shove the target to a greater height than 6 or $6\frac{1}{2}$ ft., the target is clamped at the highest graduation on the front of the rod, and the rod is extended by pushing up the back part, which carries the target with it. The readings, in this case, are made either from the vernier on a graduated side, or a vernier on the back. The rodman must always hold his rod perfectly plumb or perpendicular.

To Adjust the Level.—The proper care and adjustment of the level is of great importance. A very slight error in adjustment will completely destroy the utility of any work done.

To Adjust the Line of Collimation.—Set the tripod firmly, remove the Y pins from the clips, so as to allow the telescope to turn freely, clamp the instrument to the tripod head, and, by the leveling and tangent screws, bring either of the wires upon a clearly marked edge of some object, distant from 100 ft. to 500 ft.

Then with the hand, carefully turn the telescope half way around, so that the same wire is compared with the object assumed.

Should it be found above or below, bring it half way back by moving the capstan-headed screws at right angles to it, remembering always the inverting property of the eyepiece; now bring the wire again upon the object, and repeat the first operation until it will reverse correctly. Proceed in the same manner with the other wire until the adjustment is completed. Should both wires be much out, it will be well to bring them nearly correct before either is entirely adjusted.

To Adjust the Level Bubble.—Clamp the instrument over either pair of leveling screws, and bring the bubble into the center of the tube.

Now turn the telescope in the wyes, so as to bring the level tube on either side of the center of the bar. Should the bubble run to the end, it would show that the vertical plane, passing through the center of the bubble, was not parallel to that drawn through the axis of the telescope rings. To rectify the error, bring it by estimation half way back, with the capstan-headed screws, which are set in either side of the level holder, placed usually at the object end of the tube. Again bring the level tube over the center of the bar, and adjust the bubble in the center, turn the level to either side, and, if necessary, repeat the correction until the bubble will keep its position, when the tube is turned half an inch or more to either side of the center of the bar. The necessity for this operation arises from the fact that when the telescope is reversed, end for end, in the wyes in the other and principal adjustment of the bubble, we are not certain of placing the level tube in the same vertical plane, and, therefore, it would be almost impossible to effect the adjustment without a lateral correction.

Having now, in a great measure, removed the preparatory difficulties, we proceed to make the level tube parallel with the bearings of the Y rings. To do this, bring the bubble into the center with the leveling screws, and then, without jarring the instrument, take the telescope out of the wyes and reverse it end for end. Should the bubble run to either end, lower that end, or, what is equivalent, raise the other by turning the small adjusting nuts, on one end of the level, until, by estimation, half the correction is made; again bring the bubble into the center and repeat the whole operation, until the reversion can be made without causing any change in the bubble. It would be well to test the lateral adjustment, and make such correction as may be necessary in that, before the horizontal adjustment is entirely completed.

To Adjust the Wyes.—Having effected the previous adjustments, it remains now to describe that of the wyes, or, more precisely, that which brings the level into a position at right angles to the vertical axis, so that the bubble will remain in the center during an entire revolution of the instrument. To do this, bring the level tube directly over the center of the bar, and clamp the telescope firmly in the wyes, placing it as before, over two of the leveling screws, unclamp the socket, level the bubble, and turn the instrument half way around, so that the level bar may occupy the same position with respect to the leveling screws beneath. Should the bubble run to either end, bring it half way back by the **Y** nuts on either end of the bar; now move the telescope over the other set of leveling screws, bring the bubble again into the center, and proceed precisely as above described, changing to each pair of screws, successively, until the adjustment is very nearly perfected, when it may be completed over a single pair.

The object of this approximate adjustment is to bring the upper parallel plate of the tripod head into a position as nearly horizontal as possible, in order that no essential error may arise, in case the level, when reversed, is not brought precisely to its former situation. When the level has been thus completely adjusted, if the instrument is properly made, and the sockets well fitted to each other and the tripod head, the bubble will reverse over each pair of screws in any position. Should the engineer be unable to make it perform correctly, he should examine the outside socket carefully to see that it sets securely in the main socket, and also notice that the clamp does not bear upon the ring that it encircles. When these are correct, and the error is still manifested, it will probably be in the imperfection of the interior spindle.

After the adjustments of the level have been effected, and the bubble remains in the center in any position of the socket, the engineer should carefully turn the telescope in the wyes, and sighting upon the end of the level, which has the horizontal adjustments along each side of the wye, make the tube as nearly vertical as possible. When this has been secured, he may observe, through the telescope, the vertical edge of a building, noticing if the vertical hair is parallel to it; if not, he should loosen two of the cross-wire screws at right angles to each other, and with the hand on these, turn the ring inside, until the hair is made vertical; the line of collimation must then be corrected again, and the adjustments of the level will be complete.

To Use the Level.—When using the instrument, the legs must be set firmly into the ground, and neither the hands nor person of the operator be allowed to touch them; the bubble should then be brought over each pair of leveling screws successively, and leveled in each position, any correction being made in the adjustments that may appear necessary. Care should be taken to bring the wires precisely in focus, and the object distinctly in view, so that all errors of parallax may be avoided.

This error is seen when the eye of an observer is moved to either side of the center of the eyepiece of a telescope, in which the foci of the object and eyeglasses are not brought precisely upon the cross-wires and object; in such a case the wires will appear to move over the surface, and the observation will be liable to inaccuracy. In all instances the wires and object should be brought into view so perfectly that the spider lines will appear to be fastened to the surface, and will remain in that position however the eye is moved.

If the socket of the instrument becomes so firmly set in the tripod head as to be difficult of removal in the ordinary way, the engineer should place the palm of his hand under the wye nuts at each end of the bar, and give a sudden upward shock to the bar, taking care also to hold his hands so as to grasp it the moment it is free.

Field Work.—If the survey has been carefully made and vertical angles taken at every sight, leveling will be necessary only in cases where extreme accuracy in regard to vertical heights is necessary. In most cases of practical work at collieries, particularly in determining thickness of strata, general rise or fall of an inside road, etc., the elevations calculated by the use of the vertical angle will be close enough, but there are frequently instances when leveling must be done to insure success in certain work. In this connection it is well to state that if the transit telescope is supplied with a long level tube, and it is, as a whole, in first-class adjustment, levels can be successfully run with it, if the transitman uses due care. Having his instrument in proper adjustment and his note book ruled, the levelman is ready to proceed with the work.

The rodman holds the rod on the starting point, the elevation of which is either known or assumed. The levelman sets up his instrument somewhere in the direction in which he is going, but not necessarily, or usually, in the precise line. He then sights to the rod and notes the reading as a backsight or + (plus) sight, entering it in the proper column of his note book, and adding it to the elevation of the starting point as the "height of instrument." The rodman then goes ahead about the same distance, sets his rod on some well defined and solid point, and the levelman sights again to the target, which the rodman moves up or down the rod till it is exactly bisected by the horizontal cross-hair in the telescope, as he did when giving the backsight. This reading is noted as a foresight or — (minus) sight. The foresight subtracted from the height of instrument gives the elevation of the second station. The rodman holds this latter point, and the levelman goes ahead any convenient distance, backsights to the rod, and proceeds as before. In this case we have assumed that levels are only being taken between regular stations or two extreme points.

If a number of points in close proximity to each other are to be taken, the rodman, after giving the backsight, holds his rod at each point desired. The readings of any number in convenient sighting distance are taken and recorded as foresights, and any descriptive notes are made in the column of remarks. These are each subtracted from the height of instrument, and the elevation found is noted in column headed elevation. After all the intermediate points are taken, the rodman goes ahead to some well-defined point, which is called a "turning point" (T. P.) in the notes. The elevation of this is found and recorded. The rodman remains at this point until the levelman goes ahead, sets up and takes a backsight. This backsight reading, added to the elevation of the turning point, gives a new height of instrument from which to subtract new foresights, and thus obtain the elevation of the next set of points sighted to.

When running levels over a long line, the levelman should set frequent "bench marks." These are any permanent well-defined marks that can be readily found and identified at any future time. By leveling to them he has secured the elevation of points from which to start any subsequent levels that may be necessary. A good bench mark can always be made on the side or root of a large tree or stump by chopping it away so as to leave a wedge-shaped projection with the point up. Drive a nail in the highest point of this, to mark where the rod was held, and blaze the tree or stump above the bench mark. In this blaze, either cut or paint the number of the bench mark, which should, of course, correspond with the number in the note book. In the mines, prominent frogs or castings in the main roads, if permanent, make good bench marks.

LEVEL NOTES.

Station.	B. S.	F. S.	H. Inst.	Elev.	Remarks.
1				100.	Assumed elevation of Station 1.
	3.412		103.412		
2		4.082		99.33	Station 2 of survey. See page ...... Vol. ....
		6.791		96.621	Sight taken to ground at N. E. cor. John Smith's house.
3 = T. P.		4.862		98.55	Station 3 of survey noted above.
	11.698		110.248		
4		9.817		100.431	Station 4 of survey noted above.
B. M. 1		6.311		103.937	B. M. 1 is on north side of large white oak.
5		6.427		103.821	Station 5 of survey noted above.

In underground leveling, extreme care must be observed to record the algebraic signs of the readings, which show whether the level rod was held in its usual position, indicated by a + sign or the absence of any sign, or upside down, indicated by the — sign.

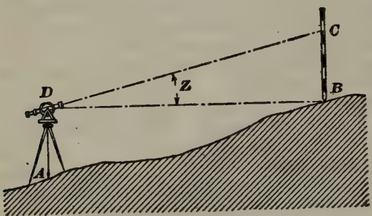
PROOF OF CALCULATIONS.—The calculations are proven by adding together the backsights and also the foresights taken to turning points and last

station. Their difference equals the difference of level between the starting point and last station. Thus:

Foresights.	*Backsights.*
4.862	3.412
6.427	11.698
11.289	15.110
	11.289
	3.821 = 103.821 — 100.0 or 3.821.

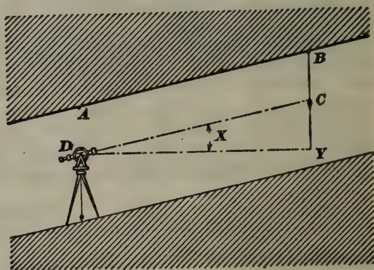
TRIGONOMETRIC LEVELING.

This method determines the difference in elevation between two points from the measurement of the distance between the points, and from the vertical angle between them. Although generally less accurate than leveling with a Y level, it is much more rapid and is especially adapted for preliminary work in a hilly country, or for the leveling of mine slopes and pitching rooms where the Y level cannot be used with any advantage or accuracy. By reading the angles and by checking the measurements a very high degree of accuracy can be obtained in trigonometric leveling.



CASE 1. Assume the elevation of A to be 100 ft. A. T. With the transit set up over A and properly leveled, sight to a point C on a rod so that BC equals AD. Measure the vertical angle Z and the inclined distance DC, then the difference in the elevation between A and B equals $BC = CD \times \sin Z$, and the elevation of B equals $100 + BC$.

CASE 2. Assume the elevation of station A in the roof of a mine to be 100 ft. A. T. Then with the transit set up directly under A and properly leveled sight to a point C upon the plumb-line suspended from the station B, measure the vertical angle X, inclined distance DC, and roof distance BC. From this, the distance $CY = DC \times \sin X$. The elevation of B is then found as follows: The elevation of $B =$ the elevation of $A - AD + (DC \times \sin X) + BC$.



There are many modifications of this simple method, but from the above diagrams the most complex modifications can be worked out.

TRIGONOMETRIC LEVEL NOTES.

Station.	Vertical Angle.	Inclined Distance.	Vertical Distance.	Height of Instrument.	Roof Distance.	Elevation.
A						+100
$A - B$	+5°	100	+8.72	2′	3′	109.72
$B - C$	+2°	100	+3.49	3′	2′	112.21
$C - D$	—3°	100	—5.23	4′	3′	105.98
$D - E$	—4°	100	—6.98	2′	1′	98.00

UNDERGROUND SURVEYING.

There are a number of variations in the foregoing practice that are caused by the entirely different set of conditions in underground work. These have been grouped together for convenience of reference.

The Establishment of Stations.—As this is the most important duty of an engineer in surface work, so it takes the first place in work underground, as the accuracy of the work depends on the location of the stations, while its rapidity depends on using the fewest number consistent with completeness. It also stands to reason that the fewer the number of stations, the fewer the chances of error. In underground work, stations should be located under the conditions of permanence, freedom from destroying agencies, and ease of access. Temporary stations for a single sight need not fill all these requirements. We establish them generally in the roof of the mine—less frequently in the floor. In the former case we must establish a "center" before each set-up of the transit, and thus underground differs from surface work. The first surveys were made with lamps set on the floor, sighted to, and then set over. Permanence was secured by driving iron nails or tacks in the sills of the track or sets of timber. As acid water soon destroyed these, they were followed by copper tacks or brads, and all were witnessed by notches cut on both sides of the sill, as in outside work, and by a vertical paint mark on the solid wall, with the number of the station. This method is faulty, as the tracks in crooked gangways are seldom placed where one can get the longest sight, and, as they are the traveling ways, the stations run the chance of being knocked out by passing men or mules, and the whole track, on a curved incline, is generally sprung by every loaded trip. As the sights must be as long as carefulness of work will allow, we put them generally in the roof, as that offers the greatest area for a choice, and is not under foot. Any settling of the roof so as to affect the accuracy of the station would be equally effective in destroying the accuracy of a station in the floor. We therefore choose places that will be least affected by subsequent work, and put the stations in collars, lids or wedges of props, in the props themselves, when they have incline sufficient to allow the transit to be set under them, or in the roof itself. Wherever set, they should not project far from the surface, and thus be liable to be brushed away in a low gangway by cars with topping higher than usual, or knocked away by flying fragments from a shot, if near the working faces. Top stations have a mark about them to call attention to their location. It is generally a circle, unless there are other corps at work in the same mine that use the circle, and the stations of the two surveys would be confused if marked alike. In this case a corps selects some easily made figure, as a triangle, square, etc. If two surveys use the same station, the mark of the second survey is placed around that of the first, and the "Remarks" give "Station No. 234 of L. & S. corps," etc.

Kinds of Stations.—The simplest top station is a shallow conical hole, made with the point of the foresight man's hatchet, which is dug into the top rock and rotated, and is called by some a *jigger* station. Corps using these entirely have a jigger consisting of a steel-pointed extension rod, with an offset holding a paint brush. The rod is long enough to allow the point to be driven into the roof at any height, and its rotation marks a circle with the brush, which is also used to mark the number beside it. Centers are set under such stations and sights are given by another tool—also called a jigger. This is an extension rod, beyond the upper end of which projects a piece of sheet iron shaped like an isosceles triangle, with the upper and smaller angle cut off so as to form an end one-quarter of an inch broad, and in this end is cut a **U**-shaped groove.

The sights are given and the "centers" set by putting the plummet cord in this groove, and placing the end in the "jigger hole" in the roof. The cord must be more than twice the length of the section of the place, as it must be held in the hand, run over the jigger notch, and hang vertically to the plummet, which must come to the floor when the stations are set. The rod and cord are held in the left hand, and the right is free to steady the "bob," give sight, or set the center. The advantage of this method lies in the quickness with which the centers are set and the sights given, and the ease with which the highest stations are reached. The disadvantages are the impossibility of making the jigger hole perfectly conical, so that the jigger can be set in the same place on two successive sights, and the plummet cord will hang exactly in the same place.

Second.—Common shingle nails are driven into collars, or cracks in the roof. The end of the plummet line is noosed and put over the head. This causes an eccentric hanging of the plummet that may cause an error in backsight and foresight of the width of the nail head, which will be quite appreciable in a short sight. To do away with this error, a variety of nails (called *spads*, *spuds*, etc.) are made of iron or copper. Iron will not corrode in dry mines,

and is much cheaper. The simplest is made by hammering out the head of a horseshoe or mule-shoe nail, punching a hole in the flattened head for inserting the cord, and cutting off the point, so as to make the finished spad an inch long. This will bring the head near the surface without having to drill too deep a hole, and will make them unfit for lamp picks, as they are very handy for such purposes, and thousands have been pulled out to this end. Any blacksmith can furnish them for less than 1 cent each. They are driven broadside to the line of sight, or they will be liable to the same objection as the shingle nail. To remove all chance of eccentricity, a form is made with a shoulder in which a hole is drilled parallel to the length of the nail. The practice of using staples for stations is antiquated—though given in the last editions of some modern textbooks—and should never be used where accuracy is required.

Third.—All these varieties of spads are driven into a crack of the roof; but such stations cannot be called *permanent*, as the same force that made the crack will tend to open it and let the nail drop. Even if this does not happen, we shall have the water in a wet mine coming in by these cracks, and rotting the nails, or the rock at the sides of the crack, and in a month after the placing of the station, it will be unfit for use.

Fourth.—Into a hole drilled in the roof, a wooden plug is driven, and into this we drive the spad. The swelling wood clamps the same and prevents its coming out as readily as it was put in. The plugs are made of well-dried wood outside, and are carried by the man that sets the stations. The first holes were made by a jumper, and the plugs were 2 in. square and 6 in. long. The modern holes are usually made by a twist drill of as small a diameter as will do the work without bending at the shank. Such drills can be used in slates or clays; but an ordinary drill and hammer must be used in harder rocks. The average modern holes are $\frac{1}{8}$ in. to $\frac{1}{2}$ in. in diameter, while the plugs are $\frac{1}{2}$ in. to 1 in. long at the maximum. The smaller the hole, the quicker the work. All stations should be put in the roof in preference to the under side of a collar, or in any ordinary timbering. The only exception is where the roof is too poor to hold them. Such stations should be checked in extending a survey before they are used, if we wish to swear to the accuracy of our work. The engineer that believes in using collars may find himself in the quandary of the man whose company worked across their line because he started from a collar station. Since its location, the place was working and the collar was taken down and shifted end for end when replaced. *Good side notes, if consulted, would have shown him the change.*

Fifth.—A twist drill $\frac{3}{32}$ in. in diameter is used to make a hole in the roof; a piece of cord—or, better, a copper wire—is placed across this, and a hard-wood shoe peg is driven into the hole and binds the cord tight. The plummet is tied to the lower end. A cord will soon rot, and, if in the gangway, is pulled out by the drivers for whip lashes, while the wire is more permanent; but even this will be pulled out by catching in the topping of a car in a low place.

Lastly.—The use of spads is dispensed with, and all the stations put in rock roof where possible. A $\frac{1}{4}''$ twist drill makes a vertical hole 1 in. deep. Into this, when a sight is to be taken, the foresight man puts a steel clip with serrated edges. This is made by bending upon itself a thin piece of steel $\frac{3}{16}$ in. wide. When the ends are pressed together it will go into the hole, and the spring of the sides and the serrated edges hold the clip in the hole so that it is hard to pull out. The cord passes through a hole in the center of the bend and is, therefore, in the center of the hole—no matter how the clip is inserted. It is removed by pressing together the ends of the clip. This is the easiest and quickest way of working, as there is no eyehole to be freed from dirt and no knot to be tied and untied. The hanging of the plummet takes a fraction of a second, and the station will remain as long as the roof keeps up. The disadvantages are the putting of the holes inclined to the vertical by a careless man, and the many roofs that are unfit for piercing with a twist drill.

Marking Stations.—We should have some regular way of witnessing our stations. In general, a vertical line on the *rib* calls attention to a station in the floor near the side marked. A roof station has the mark around it, as has been described, and it is some geometric figure. If three regular corps are engaged in the same field and meet in the same mines, as the company corps, the corps of the individual operator, and the private corps that is looking after the interest of one or more of the land owners, they must use different signs for stations. The most common are the circle, square, and

triangle. If the "circle" corps puts in the station, it has a circle about it. The next corps uses it and puts a square about it and notes "Sta. 472 = to Sta. 742 of ( ) Corps." The third corps uses it and puts a triangle about the square, and notes "Sta. 617 = to Sta. 472 of ( ) Corps, and Sta. 742 of ( ) Corps." If the first corps uses the station again, it notes the numbers given by the two other corps, and these three numbers will aid in identifying it if one or two of the numbers are lost.

Distinguishing Stations.—Each station must be lettered or numbered so that it can be readily recognized when the subsequent surveys are made. When set it may have been at the end of a gangway, while six months later the gangway has been driven hundreds of feet from that place, chambers have been turned off in what was solid, and the place be so utterly unlike its former state that nothing but a fixed mark belonging to that station alone will enable us to recognize it. The methods of distinguishing stations vary widely. In one place the writer found that each gangway and room had a Station 1 at its beginning, and the various stations numbered 1 were designated "Grog Run 1, 2, 3, etc."; "Pat James Gangway 1, 2, etc."; and so on through the map, that showed between fifty and one hundred stations numbered 1, so that a new engineer would have had to learn the mine thoroughly before he could extend a survey. Another way is to use A1, A2, etc., up to A100, and so through the alphabet *to avoid running up too high in numbers.* A third was lettering the various sections of the mine A, B, C, etc., and the numbers begin with 1 in each and run up indefinitely.

All of the above have disadvantages, as powder or lamp smoke, mud, mold, or the misplaced ingenuity of small boys may so obliterate or obscure a mark that it will be recognized only by association with its immediate neighbors, and these may have shared the same fate. You may have only a part of the mine map with you, and because the system of marking strives to get along with as few symbols as possible, you have to go to the office, when there would have been a chance of deciphering the mark if there had been a number of figures to it. The best practice, therefore, courts large numbers, begins with Station 0 at the mouth of the slope or drift, or the foot of the shaft, and numbers consecutively in each bed. In a short time three figures are reached, while in old mines the numbers require four digits. The chances of obscuring such a mark are lessened, while the chances of our deciphering it are increased.

Centers.—When the station is in the roof, there must be something for the transit to set over, as it is easier to do so than to set under a station, and much more accurate as instruments are now made. The set-up is made over a "center." At first, a cross scratched on the floor or on a loose piece of slate, a daub of white lead on the same with a small piece of coal placed under the point of the plummet—when that had been steadied—or finally, a nail driven into a block and afterwards pointed, were used. All of these, except where the mark was on the solid floor—if they were large enough to be stable—were in the way of the observer's feet, while, if small, they were so light as to be readily displaced. It must be noted here that it is not so much the errors that we can foresee and detect that influence the accuracy of the work in our own eyes, but the chances of error from accidents that we cannot control and that cannot be readily detected. To avoid the above chances, we make the centers as small and as heavy as we can—in other words, we make them of lead. A hole $1\frac{1}{4}$ in. in diameter and $\frac{1}{2}$ in. deep is bored in a thick plank, a brad is set in its center with the head down; the hole is filled with melted lead and the brad is slightly raised to surround the head with lead, and held with pincers in a vertical position till the lead has set. The brad is cut off $\frac{1}{4}$ in. above the lead and pointed. This "center" combines weight and small size, and is generally used.

Paint.—White lead, or Dutch white, thinned with linseed oil, is ordinarily used. It is carried in a covered tin pail holding a pint. The cover has a hole large enough to admit the brush. The pail generally has to be cleaned out after each day's work, as the brush gathers dirt every time it is used. In case the paint is to be kept for a number of days, it must be covered with water, which can be poured off before using. If the ordinary paint brush has too long bristles, it can be shortened and kept from wearing by winding with fine wire to the proper length. The top should be wiped clean and dry with a piece of cotton waste before the paint is applied, or the white will be so discolored as to be scarcely visible, or if the top is dirty it will flake off, and the numbers be lost.

KEEPING NOTES.

Taking Notes.—Complete notes should be taken and recorded neatly and systematically, so that a stranger can easily follow them. Every physical characteristic, and all surface improvements should be noted and located. Every ledge of rock should be noted, its character, dip, and course of strike should be taken. In a large company there should be a separate book for transit notes and for side notes, and where many collieries are operated, a separate set of books should be used for each colliery.

However the notes are kept, we must note the following things: The numbers of the stations; the needle readings to check the vernier; the vernier reading; the dip of the sight; the distance measured, either flat or on the dip; the height of the axis of the transit from the ground; the height of the point sighted at from the ground; and all other necessary remarks to make the work plain. It is customary to have series of vertical columns headed (to suit the above) Sta., Needle F. S., Needle B. S., Vernier, Pitch, Dist., H. I. (height of instrument), H. R. (height of rod, or point to which sight was taken), and Remarks.

At the top of the page in starting a survey, there should be entered the name of the mine and of the bed where the work is to be done; the names of the regular corps employed for the work, and those that were taken from the mine to point out work or assist; the instruments used; the date of the work, and, in case it be the continuation of a previous survey, the pages where such work was noted must be set down. Such books are complete records, and can be used as time books in paying the men, or as proofs of the kind of work done in case a lawsuit requires such testimony, by showing the number of men, the instruments used, and the time employed.

Transit and Side Notes.—There are about as many methods of keeping these notes as there are engineers. These methods arrange themselves into groups, and specimens of four groups will be shown, as the most common in use in the mines:

First.—The side notes of each sight follow the transit notes of that sight, and on the same page.

Second.—They are entered in the same book on opposite pages.

Third.—The transit notes of the whole survey come first, and are followed by the side notes in the same book.

Fourth.—Each set of notes has a separate book.

The last method is the best—even if the same man takes both sets of notes, and where two men do the work at the same time, such a method is imperative. Each mine should have a separate set of books for ordinary work and special work, and such a practice gives the engineer reference notes in a portable form. Unless this is done, and if the party makes surveys in twenty different mines, the notes of two succeeding surveys in any locality are generally in separate books, and both must be carried. This applies to side notes, and four books must be carried. With a special book for each mine, no index is needed to find a certain survey, and no set of books must be overhauled. The book for that mine is taken, the date looked up, and the notes found.

The taking of side notes in an ordinary outside survey is secondary to the instrumental work; while in underground work, of ordinary character, the lines of the survey are skeletons upon which are built the side notes. The side notes are therefore of the highest value, and the forms for taking them should embrace the salient features of the underground work, so that the mapper can reproduce them faithfully even if he may never have been inside.

Forms for Transit Notes.—Suppose we are setting up at b; with backsight at a; foresight to c; deflected angle $abc = 85° 27'$ left; and that the distance bc is 421.76 ft. measured on a pitch of $+ 4° 35'$.

First Form:

Sta.	Needle. B. S.	Vernier. *A*	Vernier. *B*	Needle. F. S.	Pitch.	Dist.	Sta.
—*a* *b*	S 25° 30′ W	L 85° 27′	L 85° 26′	S 60° 0′ E	+ 4° 35′	421.76	*c*

This is read: "Set-up at b; backsight at a; foresight to c; first reading of vernier under A; second (check) reading under B; check reading by needle computed from foresight and backsight needle, etc." Some note the readings of one vernier at A, and the opposite one at B, and take only one sight. The last column for stations is sometimes omitted, and the first widened, so that the three can be entered as follows: "a–b–c."

Second Form.—This differs from the first in having but one column for the venier reading, which is not noted until two readings agree, and also in omitting the last column for stations, as noted above. In some cases the line is indicated by but two stations, the one set up at, and the foresight, as in the angle given above, b–c To note the backsight, the previous line is always taken, and under "Sta." we put "a–b," and the needle reading.

Third Form.—In this case a continuous vernier is carried and the readings are put in the second column, with the needle course on foresights as a check in the third. In the column for stations only the station at which the set-up is made is noted on the line with the readings for that set-up—the backsight going on the previous, and the foresight on the following, lines.

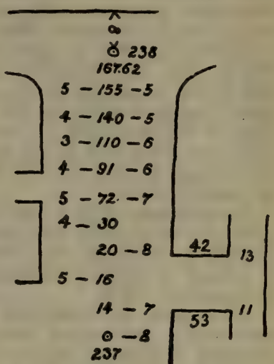


FIG. 1.

Fourth Form.—This is also a form for recording a continuous vernier, as well as the deflected angle. The right-hand page is for noting differences of level as measured by level or transit. Certain columns are filled in at the office, to make the book complete as a reference in mapping, or in the mine. This form is advocated "*for its compactness*"; but there is such a thing as too much of that article, as there is no room on either page for remarks, while in all the other systems, the right-hand page is set aside for this purpose.

Fifth Form.—Where the leveling is performed by the transit, and each sight is taken with that end in view, the level notes are added to any form of transit notes chosen and they are recorded as shown in table on page 56. These figures are used to calculate the differences in elevation, as shown by the pitch of the sight. The minus signs show that the points noted are below the stations. If the station were in the floor, the sight would have a plus sign. A continuous vernier can be used with this form.

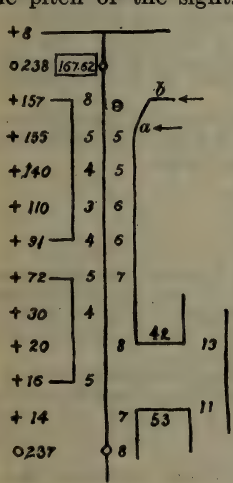


FIG. 2.

Forms for Side Notes.—In every case the notes should convey to the man that plots some idea of the form of the place surveyed. An accurate sketch cannot be made unless the whole locality can be seen at a glance—which is seldom, if evér, the case—and yet we must not go to the other extreme and write down the notes without a sketch; yet that is what is frequently done, and may be simply noted as the first form, and put aside as a faulty method with no good points.

Second Form.—In this, see Fig. 1, as in a sketch made as a person advances with no definite idea of the arrangement of the work, there is too frequently a running of the sketch off the page—on one side or the other, and a cramping of certain parts. Inserting the figures on the line of survey confuses the one that plots if the sketch is distorted or cramped. As the hands of the note man are dirty from rubbing along the tape, to find the numbers, it generally happens that the sketches are smeared and blurred so that they are hard to decipher when the notes are most clearly kept, and a method that encourages cramping, confusion, or obscurity must be rejected.

Third Form.—There is no attempt made at sketching in this form, Fig. 2, but the red line in the center of the page of the note book is taken as the line of survey, and the next parallel lines on either side are taken as the boundaries of the solid on either side. The only figures on each side of the red line are

the distances from the line to the solid, while the "pluses" at which they were taken are noted at the side of the page, and the exact distance between the two stations is enclosed in the parallelogram. This method at the pluses 155 and 157 calls attention to a point where practice varies greatly; namely, How shall we note the "corner of pillar"? and Where is the corner? One method calls the corner that point where the pillar begins to diverge from the gangway line, as noted in Fig. 2, at *a*, where a chamber, cross-cut, or counter starts from the gangway; a second method designates the corner as the first or last solid part met with in the line of survey, as at *b*, Fig. 2. The first is faulty, as there is no record of the gradual divergence of the pillar from the gangway line, and the words "corner of pillar" usually mean the end of the same. We should therefore call the pillar solid till the line at right angles to the line of survey is tangent to the ends, no matter whether that end be 10 or 100 ft. distant. Any one can plot side notes if accurately taken, and two persons accurately plotting such notes will reach the same result.

Level Notes.—These are kept as in outside work, as has been before stated, with the exception that, as the rod is reversed in getting the elevation of a station in the roof, the record of the reading is prefixed with a minus sign. A record of such a reversed rod, when the target is 3.78 ft. below the station, is recorded —3.78.

The shaft is measured (if deep) by a fine steel wire running about an accurately graduated wheel (a sufficient number of turns being laid to prevent slipping) and noting the number of turns before the bottom is reached. The wire may be measured before and after the operation, to insure against stretching. An aneroid mining barometer, if in good condition, will give quite accurate results if a number of trips are made between top and bottom, to give an average. In this case the barometer must be left quiet 10 or 15 minutes, to be sure that it has expanded or contracted to the proper degree. For rough measurements, the length of the winding rope between top and bottom is taken.

By one of these methods we locate a bench mark below, that is connected with the outside work and referred to tide water. As has been stated, the rod must be reversed to get the elevation of all stations in the roof, and all such readings are noted with the minus sign, as —4.32′ (read 4.32 ft. below station). We must bear in mind that roof stations are almost certain to settle, from the pressure of the superincumbent rocks. To check such settling, we must measure the distance from roof to floor accurately. Some measure from floor to rail of track. This is inaccurate, as the track may be shifted or the grade changed in making repairs, or to take out a "sag." A noted expert once swore that the roof had settled in a mine, as his measurements were from roof to track, and the latter had been raised without his knowledge.

Whenever we begin a level survey, we must measure the distance between roof and floor and see if it agrees with the notes. If it differs, we must note the fact under the original notes, as a check for future work.

STOPE BOOKS.

By Joseph Barrell.*

In large metal mines, where the veins are more or less vertical and great volumes of ore are extracted from between the levels, it becomes important to adopt such a system for recording the shape and location of the stopes that at any future time the engineers may be able to give precise information concerning them, without entering the mine for the purpose.

Preparation of the Stope Book.—Although the timbering furnishes means for sketching and locating the stopes, some regular system must be followed or inextricable confusion will result. The book must connect the stope sketches with the transit work of the drifts and also the various floors with one another.

Fig. 1 is a hypothetical map of a portion of two levels. Figs. 2, 3, and 4 follow from it, Fig. 2 being one leaf from the stope book. The paper should be of the quality of that used in field books, ruled by the printer vertically and horizontally, with waterproof lines in a colored ink—preferably green. A convenient scale has been found to be 4 lines to the inch, every fourth or

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* See "Mines and Minerals," October, 1899, page 97.

fifth line to be heavier. Each square will represent a square set, giving an actual scale of about 20 ft. to the inch. A smaller scale does not show enough detail, and a larger one is not necessary for this class of work.

The most convenient size for the bound books is 11 in. long by 5½ in. wide. Only the right-hand leaves are numbered, so that when open a page extends entirely across the book, 20 in., showing 400 ft. of the length of the vein and wide enough for two floors on one page. The floors immediately above each other must follow on consecutive pages; thus, on the first double page will be 400 ft. of the sill floor and first floor, on the second page the second and third floors, and on the seventh page the twelfth and thirteenth floors. The eighth page is reserved for cross-sections of the vein, and the ninth for the long upright section, these two being shown by Figs. 3 and 4. The next 400 ft. of the same drift will be shown on page 10, so that it joins on to page 1 on one side and to page 19 on the other, and in this way the work of one level is kept together. For convenience, the book should be indexed by placing a projecting tag with the number of the level on each page of the drift floor.

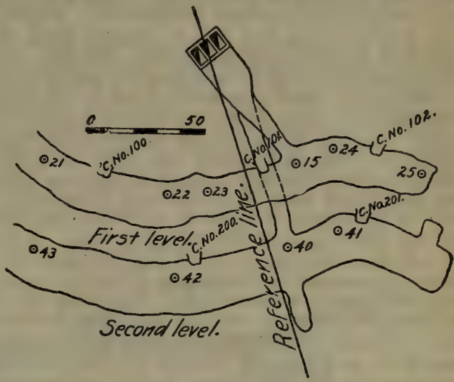


FIG. 1.

Having now a general idea of the arrangement of the work in the book, it remains for us to determine precisely, how to place it and how to show the relation to the transit surveys. First, it is necessary to have some reference line on the vein. For this purpose draw on the map, through the center of the shaft, a line perpendicular to the strike of the vein, as shown in Fig. 1. Scale off from the map the distance at which it cuts the transit course from the nearest station. Then, by adding the known distances between stations to this, we obtain the surveyed distance of any point on the drift from our reference line. Select the middle or end of a page in the stope book for the zero or reference line, such that the drift will go most conveniently in the book, and on the upper line locate the survey points at their proper distances from it, as in Fig. 2. The vertical location of any part can be told when the dimensions of the timbering are known. In this instance the drift is 7 ft. 10 in. high, and each of the following 12 floors are 7 ft. 2 in. If the levels are exactly 100 ft. apart, the thirteenth floor will consequently be 6 ft. 2 in. in height.

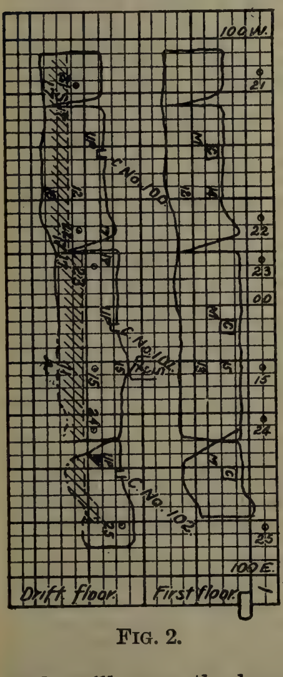


FIG. 2.

The Stope Book in the Mine.—Having indicated in the office, by a regular system, the place for everything that will be found in the mine, the next step is to proceed to the details of sketching. The location of the stations on the top line of the drift-floor pages shows on what vertical line they should lie in the sketch; but the fact that each square must be kept as representing a square set, and that any or all of them may not be exactly to our scale, will cause the location made in the mine to vary slightly from that made in the office. Any such discrepancy must be taken upon the edge of the page. Therefore, proceed to the station nearest the center of the page

and locate it as nearly as possible under its position at the top, remembering that the sets of timber, no matter how irregular, must be represented as squares. Now walk along the drift, watching the character of *one* side at the line of the *floor*, sketching while walking, counting the sets, and indicating the posts by dots of the pencil. Check up the number of sets on each station and continue to the end of the drift. Sketch the other side in coming back, and by counting the sets a second time, from station to station, a further check is placed upon the work. On the correctness of the sketches of the drift floor that of the overlying stopes depends.

Having finished the drift, climb to the first floor and locate the set climbed through the same distance east or west of the reference line as on the drift below, see Fig. 2. Since the chutes and manways will ordinarily not step off sideways, but only along the dip, a chute will be represented the same distance from the side edge of a page on all those floors where it occurs. In this way each floor is located in longitude. To do the same in latitude it will be necessary to give an arbitrary number to that row of timbers on the ground floor against the hanging wall. It is well to start with 10, since then, on a wider working of the hanging wall, there will be no danger of running down into negative numbers. The rows are numbered consecutively as they step off toward the foot-wall. Thus, in Fig. 2, on the drift floor, the manway to chute No. 102 is in row 14, and that determines the numbering on the first floor. On the thirteenth floor, in this instance, as shown in Fig. 3, the manway is in row 19. In such a manner each floor is completely located with reference to the drift below and ultimately with the transit survey.

The ease and rapidity of the work will depend on the character of the mine. Much is gained by practice, the work not being sketched set by set, but a pause for sketching being made every fifth or tenth set, or wherever there is a change in the character of the wall. In drifts such as are usually found, from 3,000 to 8,000 ft. of sketching is a good day's work. The sketch should be taken at some definite horizon, and that of the floor level is best. Features of constant recurrence must be represented by conventional signs. Thus, in Fig. 2, *c* enclosed by a square indicates a chute passing through the floor; *up* means a ladder up; *M*, a manway down. A full line indicates a rock wall, a broken line, lagging; cross-hatching represents filling; a dashed-and-dotted line, the presumed limit of filled workings, etc. It is of importance to indicate irregularities in the timbers. If it is a short set, write *S* within the square; if a long set, *L*, giving the length if necessary. If there should be an angle in the timbering so that there may be a set more on one side of the drift than on the other, represent it by a wedge-shaped opening, as shown, being the appearance of the drift if it were straightened out. In sketching, it is essential to accuracy that the attention be held to a few things at a time. On reaching the top of the raise the plan views are completed, each floor having been sketched on the way up. On descending, turn to page 8 and sketch the cross-section of the manway, as shown in Fig. 3. Each set is still represented by a square, although the sets are higher than wide, but since that fact is known it can lead to no error.

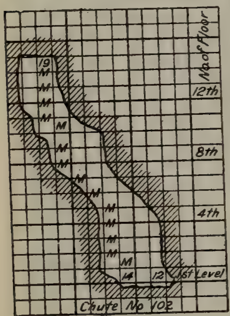


FIG. 3.

The stope book is taken through the mine and brought up to date at the first of each month, and it is necessary for the foreman or shift boss to accompany the engineer and point out each place where work has been done. To pick up the work readily, and identify the last set of the previous month, the last cap should have a notch cut in it and the same indicated in the book.

The Long Section.—The view of the vein that will be of most general use, and show at a glance the progress of the work of ore extraction, is the *long section*. It is a modified vertical projection of the vein, such as would be obtained if the rock on the hanging-wall side should be removed and the vein viewed from a distant standpoint at the same level. Fig. 4 shows the final section made in the office to the same scale as the map, but each part of it for the corresponding 400 ft. of a level will be placed on pages 10, 19, etc. of the stope book, and is compiled from the sketches of each floor. The long sections can be drawn from the plan views of the floors either in the

mine or the office, but it is a little better to determine the *limiting* points in the mine. The transit stations, chutes, and raises should, of course, be located upon it as common points with the map, connecting the two. The final long section is drawn by merely piecing together the several parts from the stope book and drawing them horizontally and vertically to the same scale.

Since a vein is quite an irregular surface, the question arises as to what modification of a vertical projection will give the most accurate and convenient representation of it. That devised by Mr. A. A. Abbott, of which the essential feature is the horizontal adjustment space left between the levels, is shown in Fig. 4. At our reference line, in this case the projection of the shaft upon the vein, the zero points of the levels are placed over each other. But owing to the warpings in the vein, a raise, such as No. 201, started, in this case, 40 ft. east, will not break through on the similar point of the level above. The simplest way in which to allow for these discrepancies is to draw the levels more than their true distance apart by the width of an adjustment space, lay out each level at its true length, and draw the raises perpendicular to them, provided, of course, that the raises only step off along the dip and not along the strike. All these features can be appreciated by studying Figs. 1, 2, 3, and 4 in connection with each other. Lines corresponding to the height are ruled on the sides of the drawing, and the floor on which the work is being done is ascertained by means of a parallel ruler. Such a view approximates to a *development* of the vein horizontally, but vertically to a *projection*, since the vein is projected on a series of vertical planes passing through the transit courses. The drifts are shown at their true lengths, but the heights are the vertical distances and not the lengths up the dip.

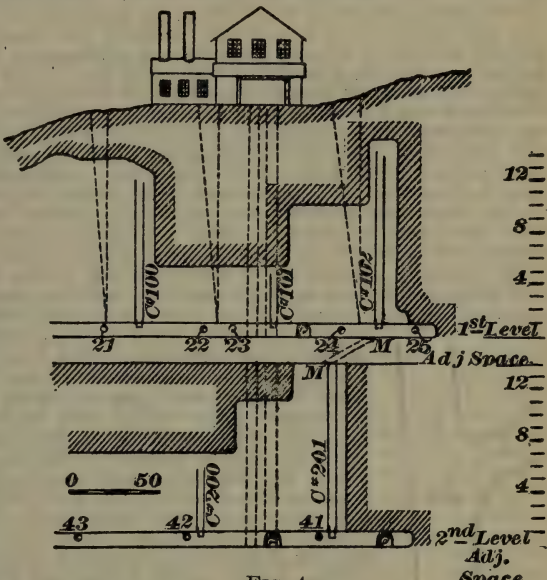


FIG. 4.

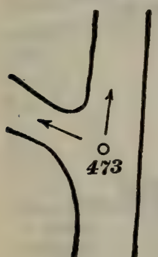
The long section will be brought up to date every 3 or 6 months, and the portions of the veins extracted during the interval indicated by cross-hatching or tinting. In the illustration, the ore bodies are cross-hatched to bring them out more clearly, but to do this on the regular map would involve erasures with every extension in the workings. In the mine, a hard and sharp drafting pencil will be used, but pencil markings in a book constantly in use soon become faint and blurred. It is necessary to go through the book at intervals and ink in everything with waterproof drawing ink. Two colors can be used with advantage, red for all transit lines and survey figures, and black for the stopes and those symbols relating to them. If there are several splits to a vein, sometimes worked together and sometimes not, the work on the different splits can be readily distinguished on the *long section* by using red for the hanging-wall split, and blue for that of the foot-wall. If old filling is taken out, such as ore, as frequently happens, the parts extracted can be cross-hatched in red, and thus a record of both the first and second extractions preserved.

The value of these methods over mere sketches made without system lies in their accuracy. Where the timbering is irregular, the accuracy of the results depends largely upon the time and care taken in the work.

MINE CORPS.

The method of dividing the work in an underground survey depends on the size of the corps. We will therefore consider the work of each man, in order to get the right number for the corps. The chief of the party should be where he can do the most good, and where he can plan the work for his subordinates. The principal point of the survey is the setting of the stations so as to do the work thoroughly with the fewest set-ups, and thus diminish the chances of error in instrumental work. The chief should locate the stations and add all the necessary signs to show how the work is to be done. The *transitman* should not have his attention distracted from his particular work by questions as to procedure. He should work untrammeled. The chief, therefore, should not run transit. Upon this basis the ideal mine corps works, and such a corps consists of at least four, and better five, men from the office, and three from the mine. It is divided into two sections. The chief takes the men supplied by the mine—one or more of whom are acquainted with the work done since the last survey—and locates the stations; the transitman follows with the second section, to measure angles and distances. By this time the stations are set and the chief takes his men after the transit party and gets the side notes, with a check measurement of the distances between stations.

Such a corps goes to the end of the former survey and identifies the last two stations. The transitman prepares to set up at the last, while the chief and party goes as far as he can see the light from the last station, or to some intermediate point from which one or more sights are to be taken. He then stops and sends a man along each place where a sight must be taken, as long as their lights are plainly seen from top to bottom where he is standing, and over this place he marks a point for a station to be inserted, and generally inserts it himself unless he be pushed by work, and must leave it for another to do, when he places a circle about the dot, places the number at the side, and as many arrows as there are new stations, the longer arrow generally pointing to the sight to be last taken and where the transit is to be set up next. Leaving a backsight at the point just set, he sets, successively, stations at the points where the foresight men have stood, in the manner just described, until he has covered the new work—the mine boss or some intelligent miner going with him to give him an idea of the "lay of the ground," so that the work can be covered with the fewest number of stations. Sometimes the chief takes the side notes and measures the distances between stations as fast as they are set. In a pitching place, a circular brass protractor with small plummet is hung at the center of a stretched tape, to give the angle at which the tape is held; this serves as a check to the measurements of the transit party, which are taken as the basis of the work, and the other measurements are solely as checks. In flat work, both measurements should coincide.



In a small corps, and where time is of little importance, the foresight man puts in the stations ahead of the transit, and while he is so doing the transitman takes the side notes. Sometimes the side notes are taken by the same man, while one of the party is taking the transit to the next station and setting it up for the next sight. There are about as many variations from these two methods as there are corps.

The *foresight man* should be intelligent and active, as the amount of work done in a day depends on his ability to *keep ahead of the transitman*. Some of the latter are fast enough to keep two foresight men *on the jump*. His duty is to set the center for the next set-up under the station, and also place the tripod if three are used in the work, to give the sight, and, in some corps, to carry the front end of the tape and assist in taking the distance. In some corps he also carries the bag with tools for setting stations, so that he generally has a load that makes rapidity of movement difficult, and anything that will diminish the weight carried will tend to quicken the work.

The rapidity with which good work is done varies considerably, but it depends on the activity of transitman and foresightman, and a good corps should have no trouble in making twelve set-ups an hour, and taking two or three sights from each set-up. It varies also with the distances between stations. The saving of time should never be sought at the expense of accuracy in the work; it is to be gained by rapidity of moving about, in

setting transit, center, etc., and in hanging plummets to give sight. The foresight man and backsight man should be in position to give sight before the transitman is ready, so that he can turn his instrument on one or the other and find them in position. The slowest parties were those that carried empty powder kegs (in the days when loose powder was allowed inside) for seats, and spent the greater part of the time sitting on them.

The backsight man has little to do inside, and to compensate for this, he is the one that cleans and oils the tape, gets out new plummet strings, and sees that the tools are ready for the next work, as soon as the corps gets to the office.

The transitman cleans the transit, unless the corps has subordinates that can be trusted with so delicate an instrument. The blackening from sulphureted hydrogen is rubbed from the silvered surfaces with whiting, and the oil or paint smears are removed with alcohol. Alcohol should be used instead of water for cleaning the instruments, and especially the lenses, which are wiped with jewelers' cotton or soft chamois skin.

SURVEYING METHODS.

Outside Surveys.—We have spoken of the points necessary to include in the survey outside, and how the base line is established. It remains to call attention to several points that must be known before the surface plant can be protected from settling, from the removal of the deposit below. The exact location of all buildings, lakes, ponds, rivers, railroads, etc. is not only necessary for the making of a correct map; it is necessary for the determination of the amounts and location of the beds that must be left untouched by the subsequent mining. Here must be mentioned an error that generally governs the location of the retaining pillars to support the above and prevent damages to themselves or to the mine. The settling of the ground would make all bodies of water leak into the mine, and also destroy to a greater or less degree all surface plant, as well as throw out of plumb all shafts or other openings for hoisting, if it did not close them entirely. The usual custom is to extend vertical planes through the boundary lines of such objects, and leave untouched all parts of the superincumbent beds embraced by those planes. This is accurate only when the strata are horizontal or vertical, as beds settle normally to the planes of the strata and not in a vertical line in case the open spaces are stowed. If the spaces are left open, they are first filled by falls, and then the settling goes on according to the above rule. No cut is necessary to show the method of settling, and the place where the bed is to be left untouched may be found as follows: *Draw a vertical section through the point to be supported, and also the underlying bed on the line of the dip of the bed—the section being accurately drawn to any scale. Draw through the extremities of the object to be supported, lines to the bed, which will make right angles with it. The space included will give the dimension of the pillar measured along the dip of the bed, and the dimensions of the object taken at right angles to the first plane will give the other dimension of the pillar.*

Inside Surveys.—As the beds of anthracite lie at all angles with the horizontal plane, the methods of surveying them vary accordingly, and can be divided into *flat* and *pitching* work. *Flat work* is where the beds have so slight a dip that the cars can be drawn to the face of the room, and where there is nothing to prevent a sight to that face from the gangway. The variations in the methods of work in this case depend on the accuracy with which the work must be performed, as, in some cases, the workings are approaching the boundary line of the property, and the sides of the rooms must be located accurately. In general, the rooms are driven at right angles to the gangway, unless the dip is too great to haul a car to the face on that line, when they are inclined to the gangway at an acute angle. The width of the rooms in flat work is generally uniform where the roof is good, but where the roof is poor the entrance is narrowed for a short distance (to better support the gangway) and then widened to the full width, or the whole is driven to the limit narrow, and the side is robbed when the top is drawn, and the whole room caves in. This last must be surveyed before the robbing begins.

The most accurate method of survey is to run a line along the gangway and put a station at the entrance of each room, whence a sight is taken to the face. This may be varied by putting the stations at alternate rooms

and measuring through the cross-cuts to get the thickness of the pillars of the intermediate rooms, or placing stations at every third room and measuring the thickness of pillars and width of rooms that intervene; or, finally, by running out the gangway with as few sights as possible and paying no attention to the positions of the rooms in setting stations, thence up to the last room to the face, and back through the cross-cuts nearest the face to the former work, where a tie is made. When opportunity offers, sights are made from the face of the rooms to the stations in the gangway for immediate ties. In case a gangway and airway have been driven considerably ahead of the rooms, it is always necessary to run lines out each and tie at the last cross-cut. This must be done in every case where the gangway is approaching the boundary line, or old workings that have been abandoned and are full of water. In addition to this check the miners must keep bore holes 20 ft. ahead in the line of the gangway, and every 20 ft. must drive others from the corners of the heading at an angle of 30° with the line of the gangway. In this way there will be no danger of running into "a house of water," as the Cornish miners call it, if the survey be inaccurate.

Pitching Work.—When the bed pitches so that a car cannot be run to the face, and when there is a good deal of firedamp in the mine, it is generally difficult to see from the gangway to the face, where the roof is good and the room straight, as a buggy track or chute, or both—when the pitch is slight—fill up the room, and, where the pitch is great, the gangway pillars generally run across the face, or there is a "battery" shutting off the bottom of the room, so that the face can be reached only by several sights. Where the roof is poor, the obstructions are increased, as the rooms are driven narrower, or, if wide, have center props and stowing in the center. If the coal is full of slate, or if the partings are thick, a large part of the room is taken up with piles of "gob," and with a very poor roof the body of the room that has been worked out is filled with the fallen roof, and the coal sent out through the triangular manways, where it is almost impossible to take a sight.

Work of this kind is surveyed by lines out gangway and back through the faces of the rooms, which are generally clear, even if the bodies of the rooms are filled with the fallen top. Where chance favors, sights are taken to the gangway; but this very seldom happens, as the two lines are as effectually separated as if in different mines. From the stations in the faces, lines are run down the rooms as far as possible to get their direction and to locate the cross-cuts. The very worst case of all is where two beds are separated by a thin parting of rock and the gangway is driven in the lower one alone, the rooms in the upper one being worked by rock chutes into the rooms below, or into the chutes from those rooms. This class of work is hard to ventilate, and to survey where the rooms above are ventilated by the air system of the lower beds; but is readily mapped where there is an air system for each bed.

Closing Surveys.—To diminish the chance of error and to furnish a ready check, the survey must be closed upon itself or some part of a former survey with every twelve new stations. With good work the error in arc in a close should not exceed 1′, and the error in position should be less than 6 in. Errors must not be "balanced"; they must be detected and rectified by running the line again, if they are not readily seen from the methods to be given. If an incorrect survey be balanced, each subsequent one must be altered to fit this incorrect work, though it may be correct in itself, and we never know where our work really stands. It is well, therefore, to check the work in arc as soon as we make a close and before the party leaves the place, as it is easy to rerun the work then.

CONNECTING OUTSIDE AND INSIDE WORK THROUGH SHAFTS AND SLOPES.

As the dip of the bed increases, it is less easy to make a connection, and the chances of accuracy diminish. In a survey, *R. Cos. Vert. Angle* is what locates the station with regard to former work. The greatest angular accuracy for a given value of *R* is where *Vert. Angle* = 0° and *R* = *Cos. Vert. Angle.* As the pitch or vertical angle of sight increases, the above cosine diminishes until, at a vertical sight, *R. Cos. Vert. Ang.* = 0°.

In the case of an adit level, or a slope of less than 45°, there is no difficulty beyond the want of absolute rigidity in setting up the transit, and the danger of moving it in going about it. The difficulty increases more rapidly

than does the pitch, and as *R. Cos. Vert. Ang.* diminishes, though *R* be fixed, the chances of error increase. When the slope reaches 60° there is an impracticability in running a line down a slope, as the line of collimation of the telescope strikes the graduated limb of the instrument. We can use a prismatic eyepiece and see up the slope; but cannot look down. As we have assumed that it is unnecessary to use an additional telescope, we shall have to run the line *by intermediates.* Set up at the bottom of the slope where the longest sight up the same can be secured and backsight on a station of the underground work; or set a backsight for the occasion (both stations will afterward be connected with the work below). With the prismatic eyepiece, sight up the slope on a line that will give the longest sight and, at the same time, afford a good intermediate place to set up the transit, as, on a pitch of 60° or more, it is absolutely necessary that the legs of the transit should be set solidly (in holes in the floor, or between the sills of the track) so that they will not be moved by subsequent walking about it. By this method, all the sights will be taken from one side alone, and the tripod legs can be shortened to make the sight possible without building a standing place—if the man be short-legged.

Call this station *A*; at the foot of the slope locate *B*, where the transit can be readily set up, and as far up the slope as we can see (this distance must be at least 100 ft.), and in a continuation of *A B*, locate *C*. Set up at *B* and take foresight to *C*; locate *D* under the same conditions that governed the placing of *B*, and, in a continuation of the line *B D*, place *E*. Set up at *D* with foresight at *E*, and locate *F* and *G* as before. The survey is carried by the intermediates *B*, *D*, *F*, etc., to the top, by a series of foresights to *C*, *E*, *G*, etc.

Shafts.—The term shaft in American coal-mining practice is applied only to vertical openings, though in metal mining, both in this country and abroad, it is also applied to highly inclined slopes. For such shafts, most of the methods given in the textbooks are worthless, as they are for transit work and *R. Cos. Vert. Ang.* in rare cases may be as great as 20 ft., while *R* varies from 100 to 1,500 ft. Again, to sight *down* a shaft necessitates the erection of a temporary (and therefore more or less unsteady) support for the tripod of the transit, and the chances of variation in its position as we stand on different sides of it are so great that we cannot feel sure that a movement has not taken place that will vitiate the work.

In sighting *up* a shaft of greater depth than 100 ft., there is annoyance—if not danger—from dripping water or the fall of more solid substances. In a wet shaft the object glass is instantly covered with water, and a sight is impossible. We must also have a platform to stand upon, and we cannot feel sure that this will be perfectly rigid. From all these considerations the methods with a transit are never used by engineers in the anthracite regions, and the connections are made as follows:

When the bottom of the shaft can be reached by an adit or slope in a roundabout route of such length as to render errors in measurement of distance of great importance, the angles are carried by a transit with as long sights as possible, and no distances are measured, from a point on the surface in the shaft to a point vertically below it in the mine. Sometimes the guide of the cage is taken when it has been recently set, as the guides are plumbed into position; but the better way is to suspend an iron plummet by a copper wire: sink the former in a barrel of water so as to lessen the tendency to swing on account of the pull upon the "bob" and wires from the air-currents, or falling drops in a wet shaft. The top of the barrel is covered with two pieces of plank with a semicircular groove of 3 in. radius cut out of the middle for the passage of the wire, to catch the substances whose fall upon the water would cause waves. The heavier the plummet and the lighter the wire, the less the tendency to swing. This wire can be sighted at by parties above and below at the same time, and the swing can be bisected to get the position of the wire. A number of sights that agree can be taken as accurate.

When the shaft is the only way to get below from above, it must be plumbed with two or more wires suspended as just described. With two wires, they are so hung that an instrument can be set up below in a line passing through them produced, and at a sufficient distance from them to insure an accurate sight; with more wires, the station below can be located at any point whence all the wires can be seen.

Case 1.—Two wires are used, which are located as far apart as possible. Two pieces of scantling *c d* and *e f*, Fig. 1, are spiked across the opposite corners of two compartments of a shaft to allow the cages to pass up and down

without interference. The station X is (roughly) located in a line through the corners x, x and is connected with the outside survey. From this station locate in the line Xxx two spads for holding the wires of the plumb-bobs. These are driven up to the head in the scantlings in such a way that the line of sight passes through the center of the holes in their heads. Measure the distances Xa and ab. This completes the work of the survey above ground.

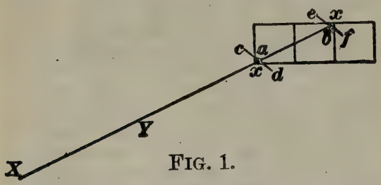


FIG. 1.

The light copper wire is rolled upon a reel, and one end is fastened to a light plumb-bob to keep it free from coils or kinks in descending. It can thus be readily lowered without accident. When at the bottom, the upper end is fastened in the spad and the heavy "bob" applied to the bottom and placed in the empty barrel. The cages are then run slowly up and down, with an observer on each, to see that the wires hang free from top to bottom. By this time the wire will have stretched so that it will be straight, and if there be any slack, it is taken up, the barrel is filled with water, and the top boards put in place. As a last check, measure the distance between the wires below and see if it agrees with the distance above.

Lining in below a point Y on the line ab, make a hole in the roof two inches in diameter, and drive in a broad plug. Setting up the transit under Y, we sight at the wires a and b alternately. A number of methods for illuminating the wires have been used, and are given in textbooks. The writer has always found those depending on a sight of the wire across the flame of a lamp the hardest to obtain, and concludes from experience that the method of illuminating the wires for mine surveying is the best for this also. A large white target is placed behind both wires and illuminated by a large lamp with a reflector behind it. The wire stands out black against it and can be followed across the target. As there is considerable distance between the wires, and as the transit is comparatively near them, there will be small chance of getting a sight of one, when the telescope is focused upon the other, and so the focus has to be set between them. This gives a hazy sight at each; but both are shown against the white background in strong relief. After the transit head is shifted so that the line of sight coincides approximately with both, focus upon them alternately and see if the line bisects the swing of each. If so, the work is done; if not, the shifting of the transit head must follow till the end is attained. It frequently requires two or more hours of steady observation to complete the work, and, when it seems as if the proper point were secured, one of the wires will show by its swaying that it has been deflected from the vertical by a peculiar slant of wind, and the result obtained must be checked again. When you are through, there is no absolute certainty that the point you have marked is in the accurate extension of the line ab at the surface. Having decided on the proper place, you drive a spad into the plug overhead; hang a plumb-bob to it, and see if it be over the axis of the transit, as shown by the screw on the telescope. If not, drive the spad so that the point of the bob does so hang, and the station Y is said to be in the line ab. Measure Ya and the angles to any station of the underground survey; the line ab is connected with the surveys at daylight and below, and the plumb-bobs may be removed.

Criticism of the Above Method.—1. As has been stated, there is no absolute certainty that the point Y is in the line ab prolonged, and this want of certainty should not exist in so important a measurement.

2. The work must be performed by daylight, and the length of time necessary to complete it makes it impossible to work the shaft for at least half a day, and may cause annoyance to the operators, or, if you are working for a lessee, lead them to refuse to let you have the use of the shaft at the time most suitable for your purpose.

3. It may be hard to obtain a long sight below on any line running through the larger axis of the shaft. Any shorter line would give too short a base line and would increase the chances of error. To avoid these, another method is sometimes used.

CASE 2.—Fig. 2 shows the top set of timbers in a shaft of two hoisting compartments, down which it is desired to carry a known course or meridian on the surface to the entry below. First find out which side of the shaft is best adapted for setting up the transit, as the point to be marked in the mines will be vertically under the point on the surface; consequently,

the side with the widest opening leading from the foot of the shaft should be selected.

Having carried the meridian to a convenient point near the top of the shaft, and having found that the south side of the shaft is the most accessible, determine, with an ordinary string, the location of the point A, from which the hangers for the plumb-lines will be exactly located by means of the transit. Now mark with chalk on the timbers where the strings cross. These marks, though not accurate, serve as guides in setting the hangers. Make a permanent station at the point A and carry the meridian to it.

The hangers can be made of strap iron, $\frac{1}{2}$ in. thick by 2 in. wide, and at least 16 in. long. In one end of the iron, have a jaw with a fine cut at the apex, or a drill hole just large enough to contain the wire to be used for plumbing. There should be two or three countersunk holes in the hanger, through which to fasten it to the timbers by means of heavy wire nails. A top view of the hanger is shown in Fig. 2.

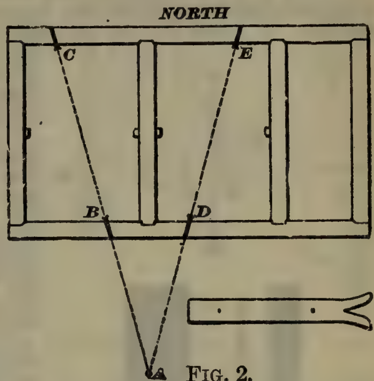


FIG. 2.

In most shafts there is a space from 2 to 4 in. wide between the ends of the cage and the sides of the timbers; and in order to hoist and lower the cage to see that the wires are hanging freely, it is best to set the hangers in such a position on the timbers that the wires will hang in the middle of the space.

Fasten the hangers permanently over the chalk marks previously made on the north side of the shaft, with the jaws pointing toward A, and on the south side of the shaft the outer end of the hanger may be fastened temporarily.

Now set the transit over the station at A, take the backsight, foresight on the wire hole of the hanger C and set the wire hole of the hanger B on the same line. Record this course and foresight on the wire hole of the hanger E, fixing as before the wire hole of the hanger D in the same line. Record this course, and then the meridian to be carried into the workings below is established. Measure carefully and record the distances A to B, A to C, and B to C, the distances A to D A to E, and D to E, and finally the distances B to D and C to E. The necessity of taking all these measurements is for the purpose of establishing a point at the bottom of the shaft vertically below A, and checking the work in the office.

The transit party can now descend to the bottom of the shaft, taking with them four buckets of oil, the weights or plumb-bobs to be attached to the wire, and all the surveying instruments, leaving a responsible party on the surface to handle the wires. Having arrived at the bottom of the shaft, have the cage hoisted 3 ft. above the landing, throw several planks across the timbers on which to set the buckets of oil, signal to the man on top to lower a wire and to fasten it securely, passing it through the wire hole of the hanger; now attach the plumb-bob and adjust the wire to such length that, when sustaining the full weight of the plumb-bob, the latter will not touch the bottom of the bucket. Insert the weight in the oil, using care not to leave the full weight on the wire with a jerk, but let the weight down slowly, so that the wire receives the full strain gradually. Set the three remaining wires in a similar way.

After the wires have been hanging a few minutes with the weights attached, the latter may move from one side to the other of the buckets. Watch this carefully and keep moving the buckets until all the weights hang perfectly free, then leave everything alone until the wires become steady. The cages can now be hoisted and lowered for the purpose of examining the wires to see that they hang free and plumb, care being taken that the cages are not brought so close to the landings as to disturb the hangers at the top, or the buckets at the bottom.

To find a point vertically below A, stretch a string along the wires B, C, being careful not to touch them; stretch another along the wires D, E; then, with a plumb-line, determine a point on the bottom vertically below

the intersection of the strings. Measure the distances $A\,B$, $A\,D$, $B\,D$, and $C\,E$ and compare them with the corresponding distances at the top of the shaft. If these distances compare favorably, the wires are, in all probability, steady, and the work of determining the desired course with the transit may now be begun.

Set the transit up over the point of intersection just found; backsight on the wires B, C; foresight on the wires D, E, and compare the included angle and the distances with the corresponding angle and distances at the surface. If these do not correspond, move the transit in the direction necessary to increase or decrease the angle or distances, as the case may be. Repeat this operation until the exact point vertically below A is determined.

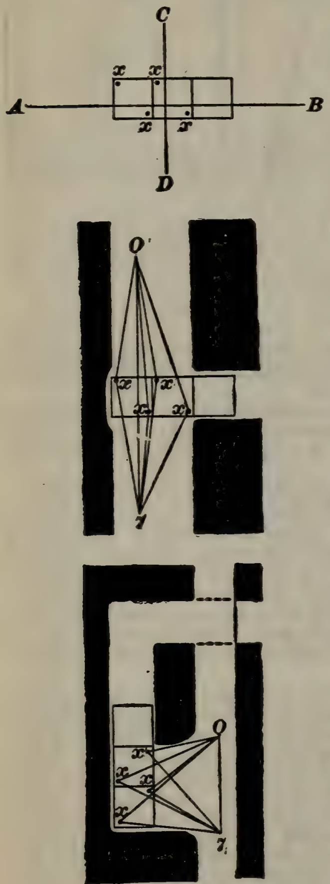


FIG. 3.

A simple device that is of great advantage is to have three links from an ordinary trace chain placed in the wires on the side toward the transit, and a few feet above the buckets. This not only enables the wires to turn freely, but also enables the transitman to sight through one of the links to the wire beyond, whereby he can place the transit in exact line with the wires more easily than if the links were not there.

CASE 3.—Two, three, or four wires are employed. They are secured and hung as before, and are located in the angles of the compartments x, x, x, x, Fig. 3. These are connected with four stations A, B, C, D, the lines $A\,B$ and $C\,D$ being at right angles to one another for convenience in the subsequent calculation, and are connected with the outside survey. From A and B, taking $A\,B$ as a base line, the points x, x, x, x are located. The same is repeated from C and D, taking $C\,D$ as a base line. We thus have four locations of each wire. These are tabulated, and any variations in a reading must be followed by a repetition of the same. The mean of the readings gives the location. (Subsequently, the subject of calculating work will be taken up.) It can be briefly stated here that the bearings of each wire to each of the others, as referred to the base line of the survey, are then calculated and the distance between the wires accurately measured. This finishes the work at daylight.

There may be two general types of arrangements of the bottom of the shaft, and both arrangements have been sketched and lettered similarly. The first is a case when the shaft is arranged across the dip of the bed, and the second is parallel to the same. In both cases O and 7 are taken as far apart as possible, and all the wires x, x, x, x located from each station with reference to the other. The distances between the wires above and below are also accurately measured as a check. There will be four locations of O and 7 from the four wires, and the mean of these is taken as the correct one. In every case of angle measurement mentioned, a series of readings of each angle is taken upon different parts of the graduated limb, to avoid instrumental errors, and the mean of these taken as the true reading. From the locations of O and 7, the course between them, as referred to the mean base line, is calculated, and $O\,7$ is the base line for the underground work. The angle readings above and below can be made at the same time with different instruments, and, in taking the readings below, it is not necessary to wait for absolute quiet in the wires, as that is seldom found. A small swing can be bisected by the cross-hair, and the readings are duplicated until a

constant result is secured. By this method a greater accuracy and speed is obtained, and the angles below can be accurately measured, no matter how the shaft may be arranged.

The T-Square Method.*—This ingenious method of taking the line underground is especially valuable in shafts with several small compartments or in cramped places where one cannot line in with the wires.

The wires are placed in separate compartments and as far apart as possible. The apparatus is made by the carpenter, and consists of a straightedge and **T** squares. The former is merely a planed pine board about 8 in. × ¾ in. and a foot longer than the distance between the wires. It rests approximately horizontally on slats tacked across the shaft for supports. It is brought to about an ⅛ or $\frac{1}{16}$ in. from each wire and then nailed to the slats sufficiently to prevent slipping. One man should be at each wire. The **T** squares are most serviceable if made with a movable head clamped by a thumbscrew, and of planed pine, about 2½ in. × ½ in. Except in cramped quarters, the **T** squares will be set at right angles, and should be placed together in clamping to insure that each is set at precisely the same angle.

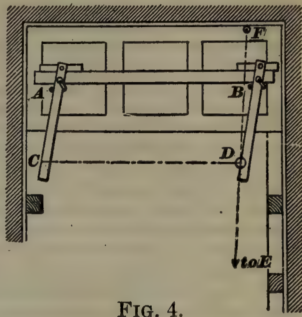


FIG. 4.

Fig. 4 shows a cramped position such as sometimes arises and in which the movable head gives more latitude in working. After clamping, the **T** squares are slid along the straightedge until close to the wire, but not touching it, and are there clamped by a "G" clamp, both men working at one **T** square. The ends of the **T** squares, *C* and *D*, must be supported on blocks so that the **T** squares lie approximately in the same horizontal plane. Everything up to the next step need be only approximately and quickly placed, but now the greatest care must be exercised in measuring out equal distances, *A C* and *B D*, from the wires. If the wire vibrates, determine the middle of its swing by a pencil or pin. Hold a footmark (not the end of the tape) opposite the wire on the **T** square, measure out an even number of feet, and mark the point with a sharp pencil, and insert a pin. This done for both wires gives us the parallelogram *A B D C*, in which the only essential is that *C D* should be exactly parallel to *A B*, the line of the wires. Now set the transit over the most convenient of the two points, as *D*. To get the azimuth of *D C*, and, consequently, the line of the wires, sight on a known point *E* for a backsight, and measure the angle *E D C*. Establish another point as *F*, on the line of the backsight, in order that its course may be preserved after the instrument and **T** square are removed.

By this means the closing angle at *E* may be read after the wires are removed from the shaft. Underground, the method is the same, except that *D C* is the known course, and is used as the backsight. To give the coordinates of the instrument at *D* with the greatest precision, the angle *A D C* and the distance *A D* should be measured.

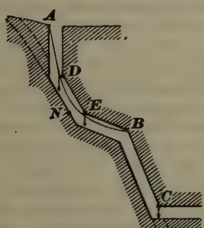


FIG. 5.

Surveying Slopes or Inclined Shafts.—Where a single sight reaches from top to bottom of the shaft, the problem is simple enough. A station can be established on the inside of the foot-wall plate at the collar and others in similar positions at each level. The instrument set up over any station can command the whole shaft and the level opposite.

Where the shaft is sunk on several dips, the survey is a much more difficult matter. Fig. 5 illustrates cases of common occurrence. The shaft may be divided into sections like *A D E B*, which are convex downwards, and others such as *E B C*, which are concave downwards. As a rule a set-up can be avoided at the convex knuckles if desired, and need only be made at those that are concave.

Bent Plumb-Line Method.—*A* may be invisible from *B*, but the survey may be

*See "Mines and Minerals," January, 1899, page 242.

carried from one point to the other by the ingenious method of the bent plumb-line.

The most complicated example which can arise is shown in Fig. 5. Establish a station at A, the foot-wall side of the collar, the center point being a small nail head projecting horizontally. Attach a long plumb-line to this and carry the other end to B. Here it will probably be necessary to use a small screw-eye, with its head turned into the vertical plane of the shaft, for the center point. Pass the plumb-line through this and draw it fairly tight. Now attach a plumb-bob at an intermediate point and regulate the tautness so that the line is clear at all points.

The curves in the shaft may be such that two plumb-bobs may have to be hung, as at D and E, and even a third may become necessary.

The plumb-line, perhaps 100 ft. long, is apt to be disturbed by the air-currents, and it is often better to mark a point on a convenient timber near D, and another near E, so close to the string that there is no doubt of the points lying in exactly the same vertical plane as the plumb-line. If these points be once established, the string and weights can be taken out of the shaft, leaving us four points in the same vertical plane, and whose horizontal projections lie in the same course.

Now set up at A and measure the azimuth angle from the backsight to D, thereby giving the bearing from A to B. If D should be invisible from B, depress the telescope after sighting on D and locate the point N in the same vertical plane, and so situated that it is visible from both A and B. Measure the *vertical* angle and distance to N. Now set up at B, use the course $B\,E$ for a backsight, and foresight to C. Measure the vertical angle and distance $B\,N$. It is seen that $B\,N$ might have been used as a backsight, and E only serves as an additional check. N is really an intermediate station, but since it lies in the course $A\,B$, a set-up there is unnecessary. In simple cases, it is a very convenient method of carrying a survey from the surface to the first level, and a longer horizontal projection of the sight $A\,D$ can be secured than if a set-up were made in the shaft at D; but in complicated cases, such as the one shown, it may often be quicker to make the extra set-up than to use the plumb-line. In all sights for determining azimuth, keep the vertical angles as low as possible, and the horizontal projection of the course long.

Method by a Single Wire in the Shaft.—Stretch a rather fine wire, free from kinks, down the shaft, as shown in Fig. 6, being careful that it touches nowhere in the shaft. Take two plumb-bobs provided with fine round strings. Suspend one from A and the other from B so that they nearly touch the same side of the wire $M\,N$. In order to have the plumb-lines as far apart as possible, the line at B must be quite long and a can of water should be provided to keep the bob from swinging. The plumb-line is fastened to a nail B nearly in the proper position. Have a bar of wood with a block fastened to it placed to one side of B and a little below it. The block must have a hole so that a small screw bolt can easily screw through it. A spool is run on the bolt having a small groove turned in it and being sandpapered and greased so that the string will slip easily as the bolt is turned. Now, place the transit in line with the two plumb-bobs as in an ordinary case of shaft plumbing. Repeat this operation below. The plumb-bobs in both cases hang in the same vertical plane and thus the true bearings are found underground. Even the plumb-lines could be dispensed with, but the method would not then be so accurate. The instrument would be set nearly in the vertical plane passing through the wire, leveled and sighted at M. Dip the telescope until the lowest point on the wire is visible, note the amount by which the cross-hair and wire fail to coincide and shift the instrument accordingly. But if this method were tried, the two points sighted at would not be nearly so far apart horizontally as the plumb-lines, and any error in leveling would also vitiate the result. This method of the single wire, however, provides no way of obtaining the coordinates.

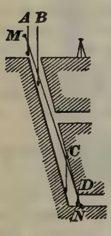


FIG. 6.

NOTES ON MAPPING.

There are no general rules governing the minutiæ of map making, so that it may be well to note some of the variations in practice. In some offices the area excavated is shown by a light wash of India ink in addition

to the ink line bounding the solid area. This makes a striking map, and the workings stand out prominently. If the survey were never to be extended and the map were simply made to show a particular state of the workings, there would be no objection to the practice; but as such extensions have to be made, and old pillars removed or cut up, it requires considerable skill to tint the extensions, and especially the surfaces when erasures have been made, so as to produce an effect uniform with the old tinted surface, especially as that tint has been deepened by frequent handling. For these reasons many offices omit the tint on the map, but some tint the back of the tracing used by the corps, or sent to the mine inspector.

It is an open question whether the *ends* of the chambers (breasts, rooms) and gangways (entries, levels) should be closed with ink. It is well to be able to show on your map where the faces of the workings were at any given time. Some place the date of each survey at the ends of the gangways at each posting, and of every fourth or fifth chamber, and thus note the rapidity with which the mine is worked. Others use various colors to denote the successive postings of the survey, and place across the ends of gangways and chambers the color appropriate to the survey that located them.

Where there are a number of beds worked from the same shaft, slope, or adit, the workings are frequently vertically above one another, and their location on the same map causes confusion unless care be taken. One of the methods used to distinguish between each bed is to line in the areas worked with a color appropriate to that bed. In this way, three or four beds have been plotted on the same map. A better way is to make a map for each bed and to combine the various beds on the tracings for the officers and the mine inspector. Each bed on this is lined with its color, and tinted with a wash of the same color on the back of the tracing on the parts excavated.

The lines of survey are lightly drawn between stations with red ink, and the stations denoted by minute circles of the same color as that used for that particular seam. The survey lines should never cut the circumference of the circle, as such a procedure might cause doubt as to the exact location of the station in case measurements were made on the map. Stations are numbered as in the mine, and beneath each is placed the elevation above or below tide of the roof of the mine. If the stations are numerous and the elevations frequently taken, such a map would furnish the means of ascertaining the shape of the bed by running contours through points of equal elevation. This plan was used by a number of engineers and was adopted by the Second Geological Survey of Pennsylvania in making their mine sheets. The adoption of the scale of 100 ft. to the inch, under the ventilation law, also furnished that survey with a means of tracing and connecting adjoining properties and their workings, as had been frequently done by large companies having adjacent collieries, and the maps of the anthracite regions of the Second Geological Survey of Pennsylvania have been thus compiled from tracings of office maps, with little or no inside work by the corps of the survey.

The ground areas of all buildings are tinted a uniform red.

All railroad tracks are represented by red lines.

All bridges, etc., and, in fact, any improvements built by man, are to be colored red.

In the mine, the stations are represented by a small circle (o) with the number in black beside it.

The lines of survey are drawn between the circumferences of the circles marking the station o————o, so as to leave the *centers* uncolored. The elevations above tide are marked.

All small bodies of water are tinted with Prussian blue; all large bodies with indigo—as Prussian blue is too vivid for large areas of tint.

It is the custom to allot a color to each bed, and make each bed on the general tracing in its color. In this way all the beds may be mapped on the same tracing, and can be distinguished though the workings may all underlie the same area. Various colors are sometimes used to denote the extent of the workings at the given postings.

The paper on which the map is made should be of the best quality, as frequent changes in the workings, and the removal of portions of old pillars, necessitate many erasures. Ordinary paper will not work well after erasure and subsequent handling, and the best practice is to use cloth-backed egg-shell paper.

It remains to note that the temperature and humidity of the office, and of the place where the maps are stored, should vary as little as possible. As the scale is small, any variation in the paper by contraction or expansion will

affect the scale on which the map was originally laid out, and will affect it unequally, as the paper is not homogeneous. This can be seen by making measurements on old maps to check work done in former times. In almost every case the 500′ squares are slightly in error. This must be guarded against in case measurements are taken from the map. It is best to calculate the distances wanted from the coordinates of the ends of the lines, and insure absolute accuracy.

A good map is the sign of a good draftsman. The title should be subordinate to the map. It is common to see the fifty-cent map of a small area smothered under a gorgeous ten-dollar title. The lettering should be neat and appropriate, and a style should be adopted that can be readily thrown off—as time is quite an item in the money made by mapping.

A neat title, the judicious use of tints over the area excavated, and good lettering of minor objects will add dollars to the value of a map. A small outlay of taste and care will make a beautiful tracing out of a ragged one, and double its value.

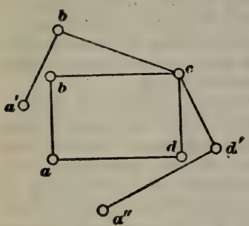


FIG. 7.

Locating Errors.—Errors in arc or distance are easily located by the method of coordinates. The transitman, at the completion of a closed survey, should sum the angles and see if it be 360°. Thus, before leaving the mine, a check will be established on the transit work. In case of a variation from 360°, the notes are examined to see if the needle readings show a similar variation with the vernier. In case the notes are incomplete, or, if a continuous vernier has been carried, we table the work before leaving the mine and locate the error as follows: Fig. 7 represents a close of four stations and an angular error at *c*. Starting from *a* we table as follows:

Sta.	Course.	Dist.	N	S	E	W	Sums.			
							N	S	E	W
a	N	100	100				100			
b	E	100			100		100		100	
c	S 30 E	100		86.58	50		13.42		150	
d (*d′*)	S 60 W	100		50		86.58		36.58	63.42	
a (*a″*)	N 30 W									
b										

There is an error in close of 30°, as the course *a″ b* differs from the course *a b* by 30°.

Reversing the order of tabling, and correcting each course by 30°, we have:

Sta.	Course.	Dist.	N	S	E	W	Sums.			
							N	S	E	W
a	E	100			100				100	
d	N	100	100				100		100	
c	N 60 W	100	50			86.58	150		13.42	
b (*b′*)	S 30 W	100		86.58		50	63.42			36.58
a (*a′*)	S 70 E									
d										

Upon comparing the sums of the northings and southings and eastings and westings in both, we find that *c* is the only station for which they agree. Here the error occurred. The location of *c* from either direction was correct, and what followed incorrect. From this we can deduce the rule:

To Find an Error in Arc.—Table the close from any station in both directions back to the initial station. The station which has a similar sum of eastings

and westings and northings and southings in both tablings is the one at which the error was made.

With two or more errors nothing can be done.

Errors in Distance.—These may be found in a close by tabling. Suppose we have a square *a b c d* so placed that the magnetic meridian passes through *b d*. Let the distance *c d* be incorrect.

Sta.	Course.	Dist.	N	S	E	W	Sums.			
							N	S	E	W
a	N 45 E	100	70.71		70.71		70.71		70.71	
b	S 45 E	100		70.71	70.71				141.42	
c	S 45 W	150		106.06		106.06		106.06	35.36	
d	N 45 W	100	70.71			70.71		35.35		35.35
a										

The first location of *a* is southings 0, westings 0; the second location is southings 35.35, westings 35.35. The westings are sines and the southings cosines, as stated before. As sin ÷ cos = tang of course referred to the base line, we divide 35.35 by 35.35 and obtain 1 as the natural tangent for 45°, and, as the error was in southings and westings, the course on which the error was made is S 45° W. The amount of the error is found by dividing the error in eastings or westings as tabled by the sine of the course just found, or the error in northings or southings by the cosine of the same. Both results will agree, 35.35 ÷ 70.71 = .50. Reducing the measured distance by this amount, we find the tabulation shows an accurate close. From this we deduce the rule:

To Find an Error in Measurement.—Divide the difference between the eastings or westings of the two locations by the difference between the northings or southings of the same. The quotient will be the tangent of the course on which the error was made. The extent of the error is found by dividing the error in eastings or westings (as tabled) by the sine of the above course, or the error in northings or southings by the cosine of the same.

Locating Special Work.—This last principle may be used for finding the proper course and distance to drive a tunnel between two stations connected by a survey. In outside tunneling, the survey is generally carried over the surface in a straight line. In underground work this is impossible, so that it is a much more difficult task to ascertain the distance and direction to drive, from the number of measurements to be made in connection with the two stations, but if the work is accurately done it is much more a feat than in outside work. To include all the elements that enter into such a calculation, we will suppose that an underground slope is to be run between two beds of coal. The distance between the two ends must be accurately obtained, as well as the relation of the two stations found. Having tabled the work, we get the difference between the sums of sines and cosines, as just described, for the two points; the quotient from dividing the first by the second gives us the course, and from the last rule the horizontal distance is found. The levels give us the difference in elevation, and from these data we get the slope per hundred, and the distance measured on that slope. All of the work is done in the mine and while the transit is setting up at one of the end stations, so that before leaving the mine, we can give the course, pitch, and distance of the tunnel and set the first station for lining in the center. The more important the work, the greater need of accuracy. In one case a 1,000′ chain was constructed to measure the distance between two shafts that were to be connected by work driven from both ends, and much of the outside work was done on the ice of the Susquehanna River, and a transit reading to 5″ was used. The work closed vertically and laterally within an inch.

Calculation of Areas.—In connection with the mapping of the part newly worked, the engineer of the company sometimes calculates the area excavated since the last posting, and estimates the royalties accruing to the various parties whose lands are leased.

This method, at best, is liable to grave errors, and requires a number of accurate cross-sections of the bed to determine its composition, as well as

numerous determinations of the specific gravity to determine its weight. The old method of estimating workable coal in a property allowed 1,000 tons per acre per foot of thickness of the bed. To obtain this amount, the roof must be good, the pillars of medium size, and the bed near the surface; or the surface must be so valueless that the pillars can be "drawn" or "robbed." As beds increase in depth, if the surface be valuable, the ratio of pillars to stall must increase or the greater pressure will cause the mine to cave in. It has been found that, when the surface is to be kept up and the workings are to be carefully driven, but 850 tons per acre per foot of thickness can be used in calculation, under the present system of mining. Efforts are constantly being made to increase this amount, with a possible chance of success.

To estimate the amount of coal excavated from any property, the best method is to institute an account of all cars of coal taken out from the workings under that property. As soon as the measurements on the mine tracing show that a gangway or room has crossed the property line, the office is notified, and all cars coming from those places are credited to that property. This is the only absolutely accurate method of computation. The total number of cars of coal run through the breaker is known, with the total weight of prepared coal. The ratio of the cars coming from a given property to the total number of cars is taken as the ratio between the total prepared coal and the coal sold from that property.

RAILROAD CURVES.

These are arcs of circles, and are divided into simple, compound, and reverse curves. A simple curve has but one radius, a compound one is continuous and has two or more radii, and a reverse one is also continuous but composed of arcs described in opposite directions.

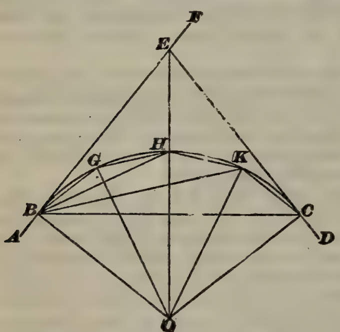


FIG. 1.

Curves are designated by the number of degrees in the central angle, which is subtended by an arc whose chord is 100 ft. long. Thus, if the angle $B\,O\,G$, Fig. 1, is 10° and $B\,G$ is 100 ft. long, $B\,G\,H\,C$ is a 10° curve.

The angle $F\,E\,C$, formed by the prolongation of two adjacent straight portions of a railroad, or *tangents*, as they are technically called, is termed an *intersection* angle.

The *deflection* angle of a curve is the angle formed at any point of the curve between a tangent and a chord of 100 ft., and is therefore one-half the size of the degree of the curve. If the chord $B\,G$ is 100 ft., the angle $E\,B\,G$ is the deflection angle of the curve $B\,G\,H\,C$, and is one-half the angle $B\,O\,G$.

When the deflection angle D is given, the radius of the curve, R, is found by the formula

$$R = \frac{50}{\sin D}.$$

The curve used to connect two tangents is determined mainly by the form of the country. When this is decided, the point of beginning, called the P. C. (point of curve), and the point where the curve ends, called the P. T. (point of tangent), must be located. Both these points are the same distance from the point of intersection of the tangents, called the P. I. (point of intersection). This distance is called the *tangent distance* of a curve, and is found by the formula

$$T = R \tan \tfrac{1}{2} I,$$

in which T = tangent distance;
R = radius of curve;
I = intersection angle.

Having set the tangent points B and C, Fig. 1, in order to locate points on the curve, set up the transit at B, the P. C. Set the vernier at zero, and sight to E, the P. I. Suppose B to be a full station on the tangent, and that it has

been decided to set stakes at each 100 ft. Let the central angle $B\,O\,G$, measured by the 100-ft. chord $B\,G$, be 10°; then, the deflection angle $E\,B\,G$, having its vertex B in the circumference, and being subtended by the chord $B\,G$, will equal $\frac{1}{2}$ $B\,O\,G$, or 5°. Turn an angle of 5° from B, which in this case will be to the right, measure 100 ft. from B, and drive a stake at G. Turn off an additional angle of 5°, making 10° from zero. and at another 100 ft. measured from G, and drive a stake at H. Continue this process until 20°, or one-half the intersection angle, has been turned off. This last deflection will bring the forechainman to the point of tangency C, or the P. T.

When the P. C. comes between two stations it is called a substation, and the chord between it and the next station on the curve is called a *subchord*. Had the P. C. been a substation, say 32 ft. beyond a regular station, the deflection angle for the measuring distance of $100 - 32 = 68$ ft. would be found in this manner: The deflection for 100 ft. is $5° = 300'$; hence, for 1 ft. it is $\frac{300'}{100} = 3'$, and for 68 ft. it is $3 \times 68 = 204' = 3°\,24'$. This is turned off and a stake set in line 68 ft. from the transit. Other stations are then located as above, by turning off an additional 5° each time.

Rules for Measuring the Radius of a Curve.—Stretch a string, say 20 ft. long, or longer if the curve is not a sharp one, across the curve corresponding to the line from A to C, in Fig. 2. Then measure from B the center of the line $A\,C$, and at right angles with it, to the rail at D. Multiply the distance A to B, or one-half the length of the string, in inches, by itself; measure the distance D to B in inches, and multiply it by itself. Add these two products, and divide the sum by twice the distance from B to D, measured exactly in inches and fractional parts of inches. This will give the radius of the curve in inches.

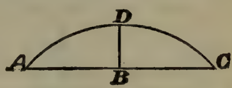


FIG. 2.

It may be more convenient to use a straightedge instead of a string. Care must be taken to have the ends of the string or straightedge touch the same part of the rail as is taken in measuring the distance from the center. If the string touches the bottom of the rail flange at each end, and the center measurement is made to the rail head, the result will not be correct.

In practice, it will be found best to make trials on different parts of the curve, to allow for irregularities.

EXAMPLE.—Let $A\,C$ be a 20-ft. string; half the distance, or $A\,B$, is then 10 ft., or 120 in. Suppose $B\,D$ is found on measurement to be 3 in. Then 120 multiplied by 120 is 14,400, and 3 multiplied by 3 is 9; 14,400 added to 9 is 14,409, which, divided by twice 3, or 6, equals 2,401½ in., or 200 ft. 1½ in., which is the radius of the curve.

The formula is thus stated,

$$\frac{A\,B^2 + B\,D^2}{2\,B\,D} = R.$$

Or, applied to the above example,

$$\frac{120^2 + 9}{2 \times 3} = 2{,}401\tfrac{1}{2} \text{ in.} = 200 \text{ ft. } 1\tfrac{1}{2} \text{ in.}$$

To Find the Radius of a Circular Railroad Curve, the Straight Portions of a Road Being Given.—If $Q\,I$ and $P\,D$, Fig. 3, are the straight portions that are to be connected, the radius of the curve $I\,D$ may be found as follows:

Produce $Q\,I$ and $P\,D$ until they meet and form the angle T. Bisect the angle $Q\,T\,P$ by the line $T\,C$. From the point on either line from which the curve is to begin, in this instance making the point I the point of curve, erect the line $I\,C$ perpendicular to $Q\,T$, and the point where this joins the line $T\,C$, or C, is the center of the curve, and the line $I\,C$ is the radius. To find the end of the curve, or point of tangent, as D, draw a line from C, perpendicular to $T\,P$. The line $C\,D$ will also be a radius of the circle of which $I\,D$ is the arc, and the point D will be the point of tangent.

To Find the Radii of Compound Curves to Join Two Straight Portions of Road. This kind of curve is adopted where the railroad is required to pass through given points, as C, D, E, F, Fig. 3 (b), or to avoid obstructions.

Compound railroad curves are composed of straight lines and circular arcs, and have common normals, $O\,H$, $O\,P$, $P\,I$, $Q\,J$, $K\,R$, and therefore common tangents where the arcs are joined. The normals are perpendicular to the straight portions of the road also; $O\,H$ is perpendicular to $A\,B$, $E\,F$ is perpendicular to $Q\,J$ and $K\,R$.

To find the radii OB, CQ, Fig. 3 (c), to connect two straight lines of railroad, AB, DE, the road has to pass from the point B, through the point C, and to touch the straight road EF at any point D.

Join B and C, make the angle $BCO = OBC$, which is supposed to be given, equal $90° - TBC$. Draw BO perpendicular to AB, then $OB = CO$, and is the radius of the arc BC.

With OB as radius, describe the arc BC; draw CF perpendicular to CQ, and produce DE to meet it in F; make $DF = CF$, and draw DQ perpendicular to EF, to meet CQ in Q. Then $CQ = QD$, and the radii OB and QD are determined.

Practical Method of Laying Out Sharp Curves in a Mine.—Curves in a mine are usually so sharp that they are designated as curves of so many feet radius, instead of as curves of so many degrees.

Suppose that it is required to connect the two headings A and B, Fig. 4 (a), which are perpendicular to each other, with a curve of 60 ft. radius. Prepare the device shown in Fig. 4 (b), by taking three small wires or inelastic strings fg, gh, and gk, each 10 ft. long, and connecting one end of each to a small ring, and the other end of two to the ends of a piece of wood $1\frac{2}{3}$ ft. long. Form a neat loop at the end f of the string gf. To use this device, lay off on the center line of the heading B, cd and de equal to 60 ft. and 10 ft., respectively. Place the loop f of the device described over a small wire peg driven in at e, and the ring g over a similar peg at d. Take hold of the stick hk, pull the strings gh and gk taut, and place the center mark on hk on the center line of the heading B. Drive a small peg in at m, located by the point k, which is on the curve. Move the device forward, place the loop f over the peg at d, the ring g over the peg at m, and take hold of the stick hk and pull until the strings gh and gk are taut, and the strings fg and gh are in a straight line. The point k will fall on the curve at n, which mark by driving in a peg. To locate other points, proceed exactly as in the last step. The distance cd in any case is found by the formula $cd = R \tan \frac{1}{2} I$, in which R is the radius of the curve, and I the intersection angle of the center lines of the headings.

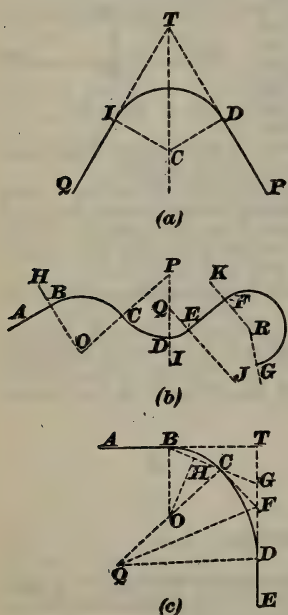


FIG. 3.

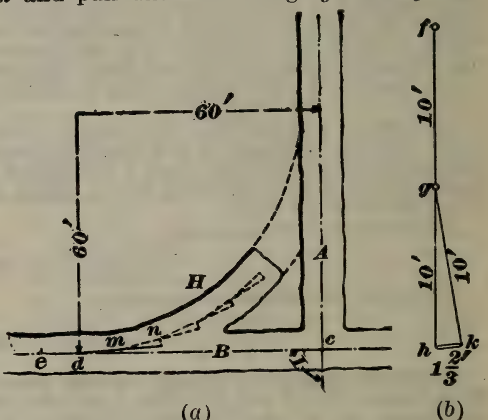


FIG. 4.

HINTS TO BEGINNERS.

Abuse of Instruments.—Surveying instruments of value and precision are not made of cast iron, as one would think from the way they are frequently handled. Underground work is transacted in places dark, dirty, and confined, so that extra care must be observed to prevent accidental knocks that damage the instrument even if they do not destroy its accuracy.

As it frequently happens that long distances must be traversed underground in going between the shaft or slope and the workings to be surveyed, the transit and level should be carried so as to obviate all accidents. They should never be attached to the tripod and carried on the shoulder, and, if the route to be passed over is up or down a slope or working place, the person carrying the instrument should be the last to descend and the first to ascend, so that loose stones or dirt that may be dislodged will not affect or endanger the instrument or trip the carrier.

Be sure that the tripod head is tightly screwed on to the tripod. The writer remembers a case where the transitman and himself, when new to the work, spent over an hour in endeavoring to obtain two readings of an angle that would agree. The variations—from 8′ to 2°—were caused by the slight movement of an old instrument with too much "lost motion," and a loose tripod head.

A great many engineers prefer kerosene to fish oil for their lamps. Kerosene never drops upon your book to make an unsightly smear, and perhaps obliterate part of your notes. A kerosene lamp is hotter and, with the glazed mine hat, is more apt to produce headaches. The writer, during the latter part of his underground work, wore a straw hat, had a piece of thin sheet brass riveted to its front with a hole in the top for the lamp hook. To the lamp was brazed a narrow cross-strip of the same metal, and the strip ends, bent back upon themselves, were slid down the sides of the plate on the hat and kept the lamp from swaying. With such an arrangement it is not necessary to remove the lamp to read the vernier, and when the lamp is used for other purposes, the hat can be removed with the lamp fastened to it. This arrangement keeps the hands free from lamp smoke or oil, and a cleaner note book is the result.

When there is an antipathy to a lamp upon the head, and when, with a long, wooden handle, one or both hands are free in going about the work, a larger lamp is used of "torch" pattern, employed by wheel testers or engineers in railroad practice. Kerosene can be burned in this. The handle can be tucked under the left arm while taking side notes. Such a lamp is convenient in finding old stations in a high place, when there is no firedamp.

For plumbing wet shafts, kerosene resists the extinguishing power of water better than fish oil, and is less readily blown out by a strong ventilating current. It makes more smoke, and, in tight headings, or mines with poor ventilation, with a large party, fouls the air much more readily than fish oil. Sometimes a mixture of the two is burnt in very drafty places, where it is hard to maintain a light. Kerosene is burned in the plummet lamp unless it is used with the "safety" attachment. Sweet oil, or any oil burning without smoke, must then be used. Smoke clogs the openings in the gauze, restricts the entry and escape of gases, and, especially if the gauze be damp with oil, may ignite and communicate the flame from within to the outside body of gas.

White lead or Dutch white (white lead and sulphate of baryta in equal parts) is best for painting stations. Zinc white has been tried with less success. The mixture should not contain too much linseed oil—especially in wet places—or it will run and destroy the witness.

THEORY OF STADIA MEASUREMENTS.

By Arthur Winslow.*

Late Assistant Geologist, Second Geological Survey of Pennsylvania, State Geologist of Missouri.

The fundamental principle on which stadia measurements are based is the geometrical one that the lengths of parallel lines subtending an angle are proportional to their distances from its apex. Thus if, in Fig. 1 (a), a represents the length of a line subtending an angle at a distance d from its apex, and a' the length of a line, parallel to, and twice the length of, a subtending the same angle at a distance d' from its apex, then d' will equal $2d$.

* Mr. Winslow's calculations and tables have been proved practically correct by the several corps of the Second Geological Survey of Pennsylvania. The corps in the anthracite regions, under directions of Mr. Frank A. Hill, geologist in charge, took over 30,000 stadia sights, and better results were obtained when tie surveys were made than in previous work in which distances were chained.

This is, in a general way, the underlying principle of stadia work; the nature of the instruments used, however, introduces several modifications, and these will be best understood by a consideration of the conditions under which such measurements are generally made.

There are placed in the telescopes of most instruments fitted for stadia work, either two horizontal wires (usually adjustable), or a glass with two etched horizontal lines at the position of the cross-wires and equidistant from the center wire. A self-reading stadia rod is further provided, graduated according to the units of measurements used. In a horizontal sight with such a telescope and rod, the positions of the stadia wires are projected upon the rod, and intercept a distance which, in Fig. 1 (*b*), is represented by *a*.

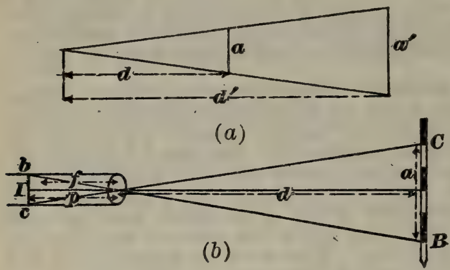


FIG. 1.

In point of fact, there is formed, at the position of the stadia wires, a small conjugate image of the rod that the wires intersect at points *b* and *c*, which are, respectively, the foci of the points *B* and *C* on the rod. If, for the sake of simplicity, the object glass be considered a simple biconvex lens, then, by a principle of optics, the rays from any point of an object converge to a focus at such a position that a straight line, called a *secondary axis*, connecting the point with its image, passes through the center of the lens. This point of intersection of the secondary axes is called the *optical center*. Hence, it follows that lines such as *c C* and *b B*, in Fig. 1 (*b*), drawn from the stadia wires through the center of the object glass, will intersect the rod at points corresponding to those that the wires cut on the image of the rod. From this follows the proportion:

$$\frac{d}{p} = \frac{a}{I}.$$

$$\therefore \quad d = \frac{p}{I}\,a, \qquad (1)$$

where d = distance of rod from center of objective;
p = distance of stadia wires from center of objective;
a = distance intercepted on rod by stadia wires;
I = distance of stadia wires apart.

If p remained the same for all lengths of sight, then $\frac{p}{I}$ could be made a desirable constant and d would be directly proportional to a. Unfortunately, however, for the simplicity of such measurements, p (the focal length) varies with the length of the sight, increasing as the distance diminishes and vice versa. Thus, the proportionality between d and a is variable. The object, then, is to determine exactly what function a is of d and to express the relation in some convenient formula.

The following is the general formula for biconvex lenses:

$$\frac{1}{p} + \frac{1}{p'} = \frac{1}{f}; \qquad (2)$$

f is the *principal* focal length of the lens, and p and p' are the focal distances of image and object, and are, *approximately*, the same as p and d, respectively, in equation (1):

Therefore, $$\frac{1}{p} + \frac{1}{d} = \frac{1}{f}, \text{ approximately,}$$

and $$\frac{d}{p} = \frac{d}{f} - 1.$$

From (1), $$\frac{d}{p} = \frac{a}{I}.$$

$$\therefore \quad \frac{a}{I} = \frac{d}{f} - 1.$$

Whence, $$d = \frac{f}{I}\,a + f. \qquad (3)$$

In this formula, it will be noticed that as f and I remain constant for sights of all lengths, the factor by which a is to be multiplied is a constant, and that d is thus equal to a constant times the length of a, plus f. This formula would seem, then, to express the relation desired, and it is generally considered as the fundamental one for stadia measurements. As above stated, however, the equation $\frac{1}{p} + \frac{1}{d} = \frac{1}{f}$ is only *approximately* true, and the conjunction of this formula with (2) being, therefore, not rigidly admissible, equation (3) does not express the exact relation.* The equation expressing the true relation, though differing from (3) in value, agrees with it in form, and also in that the expression corresponding to $\frac{f}{I}$ is a constant, and that the amount to be added remains, practically, f. The constant corresponding to $\frac{f}{I}$ may be called k†, and thus the distance of the rod from the objective of the telescope is seen to be equal to a constant times the reading on the rod, plus the principal focal length of the objective. To obtain the exact distance to the *center* of the instrument, it is further necessary to add the distance of the objective from that center to f; which sum may be called c. The final expression for the distance, with a horizontal sight, is then

$$d = k\,a + c. \qquad (4)$$

The necessity of adding c is somewhat of an encumbrance. In the stadia work of the U. S. Government surveys, an approximate method is adopted in which the total distance is read directly from the rod. For this method the rod is arbitrarily graduated, so that, at the distance of an average sight, the same number of units of the graduation are intercepted, between the stadia wires on the rod, as units of length are contained in the distance. For any other distance, however, this proportionality does not remain the same; for, according to the preceding demonstration, the reading on the rod is proportional to its distance, not from the center of the instrument, but from a point at a distance "c" in front of that center, so that, when the rod is moved from the position where the reading expresses the *exact* distance, to a point say half that distance from the instrument center, the reading expresses a distance *less* than half; and, at a point double that distance from instrument center, the distance expressed by the reading is *more* than twice the distance. The error for all distances less than the average is minus, and for greater distances, plus. The method is, however, a close approximation, and excellent results are obtained by its use.

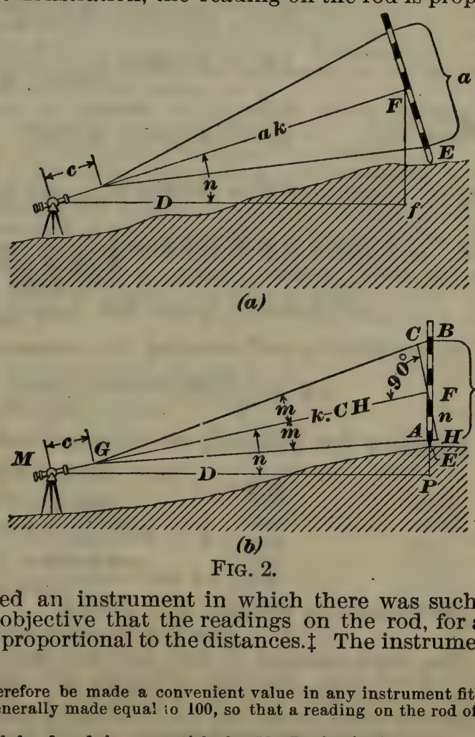


Fig. 2.

Another method of getting rid of the necessity of adding the constant was devised by Mr. Porro, a Piedmontese, who constructed an instrument in which there was such a combination of lenses in the objective that the readings on the rod, for all lengths of sight, were exactly proportional to the distances.‡ The instrument

* This is demonstrated later on.

† k is dependent on I, and can therefore be made a convenient value in any instrument fitted with adjustable stadia wires. It is generally made equal to 100, so that a reading on the rod of 1′ corresponds to a distance of $100' + f$.

‡ A notice of this instrument will be found in an article by Mr. Benjamin Smith Lyman, entitled "Telescopic Measurements in Surveying," in "Journal Franklin Institute," May and June, 1868, and a fuller description is contained in "Annales des Mines," Vol. XVI, fourth series.

was, however, bulky and difficult to construct, and never came into extensive use.

For stadia measurements with inclined sights, there are two modes of procedure. One is to hold the rod at right angles to the line of sight; the other, to hold it vertical. With the first method, it will be seen, by reference to Fig. 2 (a), that the distance read is not to the foot of the rod E, but to a point f, vertically under the point F, cut by the center wire. A correction has, therefore, to be made for this. An objection to this method is the difficulty of holding the rod at the same time in a vertical plane and inclined at a definite angle. Further, as the rod changes its inclination with each new position of the transit, the vertical angles of backsight and foresight are not measured from the same point.

The method usually adopted is the second one, where the rod is always held *vertical*. Here, owing to the oblique view of the rod, it is evident that the space intercepted by the wires on the rod varies, not only with the distance, but also with the angle of inclination of the sight. Hence, in order to obtain the true distance from station to station, and also its vertical and horizontal components, a correction must be made for this oblique view of the rod. In Fig. 2 (b),

$AB = a =$ reading on rod;
$MF = d =$ inclined distance $= c + GF = c + k.\ CH$;
$MP = D =$ horizontal distance $= d \cos n$;
$FP = Q =$ vertical distance $= D \tan n$;
$n =$ vertical angle;
$AGB = 2m$.

It is first required to express d in terms of a, n, and m.

From the proportionality existing between the sides of a triangle and the sines of the opposite angles,

$$\frac{AF}{GF} = \frac{\sin m}{\sin\,[90° + (n - m)]};$$

or,

$$AF = GF \sin m \frac{1}{\cos\,(n - m)};$$

and

$$\frac{BF}{GF} = \frac{\sin m}{\sin\,[90° - (n + m)]};$$

or,

$$BF = GF \sin m \frac{1}{\cos\,(n + m)};$$

or

$$AF + BF = GF \sin m \left[\frac{1}{\cos\,(n - m)} + \frac{1}{\cos\,(n + m)}\right];$$

$$AF + BF = a, \text{ and } GF = \frac{CH}{2}\,\frac{1}{\tan m} = \frac{CH}{2}\,\frac{\cos m}{\sin m}.$$

By substituting and reducing to a common denominator,

$$a = \frac{CH}{2}\,\frac{\cos m\,[\cos\,(n + m) + \cos\,(n - m)]}{\cos\,(n + m)\,\cos\,(n - m)}.$$

Reducing this according to trigonometrical formulas,

$$CH = a\,\frac{\cos^2 n \cos^2 m - \sin^2 n \sin^2 m}{\cos n \cos^2 m},$$

as

$$d = MF = c + k.\,CH.$$

$$\therefore\ d = c + k\,a\,\frac{\cos^2 n \cos^2 m - \sin^2 n \sin^2 m}{\cos n \cos^2 m}.$$

The horizontal distance, $D = d \cos n$.

$$\therefore\ D = c \cos n + k\,a \cos^2 n - k\,a \sin^2 n \tan^2 m.$$

The third member of this equation may safely be neglected, as it is very small even for long distances and large angles of elevation (for 1,500′ $n = 45°$ and $k = 100$, it is but 0.07′). Therefore, the final formula for distances with a stadia rod held vertically, and with wires equidistant from the center wire, is the following:

$$D = c \cos n + a\,k \cos^2 n. \qquad (5)$$

The vertical distance Q is easily obtained from the relation: $Q = D \tan n$.

$$\therefore\quad Q = c \sin n + a\,k \cos n \sin n;$$

or,
$$Q = c \sin n + a\,k \frac{\sin 2n}{2}. \qquad (6)^*$$

With the aid of formulas (5) and (6), the horizontal and vertical distances can be immediately calculated when the reading from a *vertical* rod and the angle of elevation of any sight are given. From these formulas, the stadia reduction tables following have been calculated. The values of $a\,k \cos^2 n$ and $a\,k \frac{\sin 2n}{2}$ were separately calculated for each 2 minutes up to 30° of elevation; but, as the value of $c \sin n$ and $c \cos n$ has quite an inappreciable variation for 1°, it was thought sufficient to determine these values only for each degree. As c varies with different instruments, these last two expressions were calculated for three different values of c, thus furnishing a ratio from which values of $c \sin n$ and $c \cos n$ can be easily determined for an instrument having any constant (c).

Similar tables have been computed by J. A. Ockerson and Jared Teeple, of the United States Lake Survey. Their use is, however, limited, from the fact that the meter is the unit of horizontal measurement, while the elevations are in feet. The bulk of the tables furnishes differences of level for stadia readings up to 400 meters, but only up to 10° of elevation. Supplementary tables give the elevations up to 30° for a distance of 1 meter. For obtaining horizontal distances, reference has to be made to *another* table, which is somewhat an objectionable feature, and a multiplication *and* a subtraction has to be made in order to obtain the result. Last, but not least, these tables are apparently only accurate when used with an instrument whose constant is .43 meter.

The many advantages of stadia measurements in surveying need not be dwelt on here, both because attention has been repeatedly called to them, and because they are self-evident to every engineer. Neither will it be within the compass of this article to describe the various forms of rods and instruments, or the conventionalities of stadia work.

It is seen that, in the deduced formula, the factor by which the reading on the rod is multiplied is a constant for each instrument. The question now arises, Does this remain the case with a compound objective?

In view of the difficulty of demonstrating this mathematically, it was decided to make a practical test of this point with a carefully adjusted instrument. The readings were taken from two targets set so that the sight should be horizontal, thus preventing any personal error or prejudice from affecting the reading. A distance of 500 ft. was first measured off on a level stretch of ground, and each 50-ft. point accurately located. From one end of this line, three successive series of stadia readings were then taken from the first 50-ft. and each succeeding 100-ft. mark. The following table contains the results:

Distances. Feet.	Spaces Intercepted on the Rod.			
	1st Series. Feet.	2d Series. Feet.	3d Series. Feet.	Mean. Feet.
50	.485	.4860	.4855	.4855
100	.985	.9870	.9830	.9850
200	1.985	1.9860	1.9840	1.9850
300	2.989	2.9875	2.9870	2.9878
400	3.983	3.9800	3.9890	3.9840
500	4.985	4.9850	4.9900	4.9867

Multiplying the mean of these readings by 100, and subtracting the result from the corresponding distance, we obtain the following table:

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*The above demonstration is substantially that given by Mr. George J. Specht in an article on Topographical Surveying in "Van Nostrand's Engineering Magazine," February, 1880, though enlarged and corrected.

Distances. Feet.	Mean of Stadia Readings Times 100. Feet.	Differences. Feet.	Variations From Mean. Feet.
50	48.55	1.45	+.02
100	98.50	1.50	+.07
200	198.50	1.50	+.07
300	298.78	1.22	−.21
400	398.40	1.60	+.17
500	498.67	1.33	−.10

Sum of differences = 8.60; mean of difference = 1.43.

The variations between the numbers of the column of differences are slight, the maximum from a mean value of 1.43 ft. being only .21 ft. A study of the tables will show that these variations have no apparent relation to the length of the sight, and as, in the maximum case, the variation corresponds to a reading on the rod of only .0021 ft. (an amount much within the limits of accuracy of any ordinary sight), we are perfectly justified in concluding that these variations are accidental, and that the "difference" is a *constant* value.

We thus see that with a telescope having a compound, plano-convex objective, the horizontal distance is equal to a *constant* times the reading on the rod, plus a *constant*, and may, as in other cases, be expressed by the equation

$$d = ak + c.$$

A few precautions, necessary for accurate work, should, however, be emphasized. First, as regards the special adjustments: Care should be taken that in setting the stadia wires* allowance be made for the instrument constant, and that the wires are so set that the reading, at any distance, is less than the true distance by the amount of this constant.†

For accurate stadia work, it is better to take both distances and elevations only at alternate stations, and then to take them from both backsight and foresight in such a manner that the vertical angle is always read from the same position on each rod, which should be the average height of the telescope at the different stations.

Cases will, of course, occur where this method will be impracticable, and then the mode of procedure must be left to the judgment of the surveyor. If it be desired to have the absolute elevation of the ground under the instrument, the height of telescope at each station will have to be measured by the rod, and the difference between this measurement and the average height used in sighting to the rod either added or subtracted, as the case may be. This difference will ordinarily be so small that in a great deal of stadia work no reduction will be necessary. In sighting to the rod for the angle of depression or elevation, the center horizontal wire must always be used. By this means an exactly continuous line is measured. For theoretical exactness it is necessary that the stadia wires should be equidistant from the horizontal center wire, for, if this is not the case, the distance read is for an angle of elevation differing from the true one by an amount proportional to the displacement of the wires.

With reasonable care a high degree of accuracy can be attained in stadia measurements. The common errors of stadia reading are unlike the common errors of chaining, the gross ones (such as making a difference of a whole hundred feet) being, in general, the only important ones, and these are readily checked by double readings. To facilitate the subtraction of the reading of one cross-hair from that of another, one should be put upon an

* This applies to an instrument with movable stadia wires, and not to one with etched lines on glass. In the latter case, the graduation of the rod is the adjustable portion. It has been claimed as an advantage for etched lines on glass, that they are not affected by variations of temperature, while the distance between stadia wires is. A series of tests made with one of Heller & Brightly's transits, to determine this point, showed no appreciable alteration in the space between the wires, as measured on a rod 500 ft. distant, with a range of temperature between that produced in the instrument by the sun of a hot summer's day and that produced by enveloping the telescope in a bag of ice.

† As the difference is evidently proportional to the length of sight, with a 1,000′ sight it would amount to 22.5′, etc.

even footmark, and in the check, reading the other one. This is assuming the measurements to be made by the ordinary method, and not by the approximate one of the United States Engineers.

HORIZONTAL DISTANCES AND DIFFERENCES OF LEVEL FOR STADIA MEASUREMENTS.

The formulas used in the computation of the following tables were those given by Mr. George J. Specht in an article on Topographical Surveying, published in "Van Nostrand's Engineering Magazine" for February, 1880. These formulas furnish expressions for horizontal distances and differences of level for stadia measurements, with the conditions that the stadia rod *be held vertical*, and the stadia wires be equidistant from the center wire. They are as follows:

$$D = c \cos n + a k \cos^2 n;$$

$$Q = D \tan n = c \sin n + \frac{a k \sin 2n}{2};$$

D = horizontal distance;
Q = difference of level;
c = distance from center of instrument to center of object glass, plus focal length of object glass;
k = focal length of object glass divided by distance of stadia wires apart;
a = reading on stadia rod;
n = vertical angle;
$a k$ = reading on rod multiplied by k, which is a constant for each instrument (generally 100).

In the tables, the vertical columns consist of two series of numbers for each degree, which series represent, respectively, the different values of $a k \cos^2 n$ and $\frac{a k \sin 2n}{2}$ for every 2 minutes, when $a k = 100$. To obtain the horizontal distance or the difference of level in any case, the corresponding value of $c \cos n$ or $c \sin n$ must further be added; and the mean of each of these expressions, for each degree, with three of the most common values of c, is given under each column.

As an example, let it be required to find the horizontal distance and the difference of level when $n = +6° 18'$, $a k = 570$, and the instrument constant $c = .75$. In the column headed 6°, opposite 18′ in the series for "Hor. Dist.," we find 98.80 as the expression for $a k \cos^2 n$ when $a k = 100$; therefore, when $a k = 570$,

$$a k \cos^2 n = 98.80 \times 5.70 = 563.16.$$

To this must be added $c \cos n$, which, in this case, is found in the subjoined column to be .75.

In a similar manner, the required difference of level is

$$(+ 10.91 \times 5.70) + .08 = + 62.27.$$

One multiplication and one addition must be made in each case.

It is to be noticed that, with the smaller angles, cos n in the expressions $c \cos n$ and $c \sin n$ may be entirely neglected without appreciable error.

For values of c, which differ from those given, an approximate correction, proportional to the amount of difference, may very easily be made in these two expressions.

M.	0° Hor. Dist.	0° Diff. Elev.	1° Hor. Dist.	1° Diff. Elev.	2° Hor. Dist.	2° Diff. Elev.	3° Hor. Dist.	3° Diff. Elev.	4° Hor. Dist.	4° Diff. Elev.	5° Hor. Dist.	5° Diff. Elev.	6° Hor. Dist.	6° Diff. Elev.	7° Hor. Dist.	7° Diff. Elev.	8° Hor. Dist.	8° Diff. Elev.	9° Hor. Dist.	9° Diff. Elev.	10° Hor. Dist.	10° Diff. Elev.
0′	100.00	.00	99.97	1.74	99.88	3.49	99.73	5.23	99.51	6.96	99.24	8.68	98.91	10.40	98.51	12.10	98.06	13.78	97.55	15.45	96.98	17.10
2	100.00	.06	99.97	1.80	99.87	3.55	99.72	5.28	99.51	7.02	99.23	8.74	98.90	10.45	98.50	12.15	98.05	13.84	97.53	15.51	96.96	17.16
4	100.00	.12	99.97	1.86	99.87	3.60	99.71	5.34	99.50	7.07	99.22	8.80	98.88	10.51	98.48	12.21	98.03	13.89	97.52	15.56	96.94	17.21
6	100.00	.17	99.96	1.92	99.87	3.66	99.71	5.40	99.49	7.13	99.21	8.85	98.87	10.57	98.47	12.26	98.01	13.95	97.50	15.62	96.92	17.26
8	100.00	.23	99.96	1.98	99.86	3.72	99.70	5.46	99.48	7.19	99.20	8.91	98.86	10.62	98.46	12.32	98.00	14.01	97.48	15.67	96.90	17.32
10	100.00	.29	99.96	2.04	99.86	3.78	99.69	5.52	99.47	7.25	99.19	8.97	98.85	10.68	98.44	12.38	97.98	14.06	97.46	15.73	96.88	17.37
12	100.00	.35	99.96	2.09	99.85	3.84	99.69	5.57	99.46	7.30	99.18	9.03	98.83	10.74	98.43	12.43	97.97	14.12	97.44	15.78	96.86	17.43
14	100.00	.41	99.95	2.15	99.85	3.90	99.68	5.63	99.46	7.36	99.17	9.08	98.82	10.79	98.41	12.49	97.95	14.17	97.43	15.84	96.84	17.48
16	100.00	.47	99.95	2.21	99.84	3.95	99.68	5.69	99.45	7.42	99.16	9.14	98.81	10.85	98.40	12.55	97.93	14.23	97.41	15.89	96.82	17.54
18	100.00	.52	99.95	2.27	99.84	4.01	99.67	5.75	99.44	7.48	99.15	9.20	98.80	10.91	98.39	12.60	97.92	14.28	97.39	15.95	96.80	17.59
20	100.00	.58	99.95	2.33	99.83	4.07	99.66	5.80	99.43	7.53	99.14	9.25	98.78	10.96	98.37	12.66	97.90	14.34	97.37	16.00	96.78	17.65
22	100.00	.64	99.94	2.38	99.83	4.13	99.66	5.86	99.42	7.59	99.13	9.31	98.77	11.02	98.36	12.72	97.88	14.40	97.35	16.06	96.76	17.70
24	100.00	.70	99.94	2.44	99.82	4.18	99.65	5.92	99.41	7.65	99.11	9.37	98.76	11.08	98.34	12.77	97.87	14.45	97.33	16.11	96.74	17.76
26	99.99	.76	99.94	2.50	99.82	4.24	99.64	5.98	99.40	7.71	99.10	9.43	98.74	11.13	98.33	12.83	97.85	14.51	97.31	16.17	96.72	17.81
28	99.99	.81	99.93	2.56	99.81	4.30	99.63	6.04	99.39	7.76	99.09	9.48	98.73	11.19	98.31	12.88	97.83	14.56	97.29	16.22	96.70	17.86
30	99.99	.87	99.93	2.62	99.81	4.36	99.63	6.09	99.38	7.82	99.08	9.54	98.72	11.25	98.29	12.94	97.82	14.62	97.28	16.28	96.68	17.92
32	99.99	.93	99.93	2.67	99.80	4.42	99.62	6.15	99.38	7.88	99.07	9.60	98.71	11.30	98.28	13.00	97.80	14.67	97.26	16.33	96.66	17.97
34	99.99	.99	99.93	2.73	99.80	4.48	99.62	6.21	99.37	7.94	99.06	9.65	98.69	11.36	98.27	13.05	97.78	14.73	97.24	16.39	96.64	18.03
36	99.99	1.05	99.92	2.79	99.79	4.53	99.61	6.27	99.36	7.99	99.05	9.71	98.68	11.42	98.25	13.11	97.76	14.79	97.22	16.44	96.62	18.08
38	99.99	1.11	99.92	2.85	99.79	4.59	99.60	6.33	99.35	8.05	99.04	9.77	98.67	11.47	98.24	13.17	97.75	14.84	97.20	16.50	96.60	18.14
40	99.99	1.16	99.92	2.91	99.78	4.65	99.59	6.38	99.34	8.11	99.03	9.83	98.65	11.53	98.22	13.22	97.73	14.90	97.18	16.55	96.57	18.19
42	99.99	1.22	99.91	2.97	99.78	4.71	99.59	6.44	99.33	8.17	99.01	9.88	98.64	11.59	98.20	13.28	97.71	14.95	97.16	16.61	96.55	18.24
44	99.98	1.28	99.91	3.02	99.77	4.76	99.58	6.50	99.32	8.22	99.00	9.94	98.63	11.64	98.19	13.33	97.69	15.01	97.14	16.66	96.53	18.30
46	99.98	1.34	99.90	3.08	99.77	4.82	99.57	6.56	99.31	8.28	98.99	10.00	98.61	11.70	98.17	13.39	97.68	15.06	97.12	16.72	96.51	18.35
48	99.98	1.40	99.90	3.14	99.76	4.88	99.56	6.61	99.30	8.34	98.98	10.05	98.60	11.76	98.16	13.45	97.66	15.12	97.10	16.77	96.49	18.41
50	99.98	1.45	99.90	3.20	99.76	4.94	99.56	6.67	99.29	8.40	98.97	10.11	98.58	11.81	98.14	13.50	97.64	15.17	97.08	16.83	96.47	18.46
52	99.98	1.51	99.89	3.26	99.75	4.99	99.55	6.73	99.28	8.45	98.96	10.17	98.57	11.87	98.13	13.56	97.62	15.23	97.06	16.88	96.45	18.51
54	99.98	1.57	99.89	3.31	99.74	5.05	99.54	6.78	99.27	8.51	98.94	10.22	98.56	11.93	98.11	13.61	97.61	15.28	97.04	16.94	96.42	18.57
56	99.97	1.63	99.89	3.37	99.74	5.11	99.53	6.84	99.26	8.57	98.93	10.28	98.54	11.98	98.10	13.67	97.59	15.34	97.02	16.99	96.40	18.62
58	99.97	1.69	99.88	3.43	99.73	5.17	99.52	6.90	99.25	8.63	98.92	10.34	98.53	12.04	98.08	13.73	97.57	15.40	97.00	17.05	96.38	18.68
60	99.97	1.74	99.88	3.49	99.73	5.23	99.51	6.96	99.24	8.68	98.91	10.40	98.51	12.10	98.06	13.78	97.55	15.45	96.98	17.10	96.36	18.73
c = .75	.75	.01	.75	.02	.75	.03	.75	.05	.75	.06	.75	.07	.75	.08	.74	.10	.74	.11	.74	.12	.74	.14
c = 1.00	1.00	.01	1.00	.03	1.00	.04	1.00	.06	1.00	.08	.99	.09	.99	.11	.99	.13	.99	.15	.99	.16	.98	.18
c = 1.25	1.25	.02	1.25	.03	1.25	.05	1.25	.08	1.25	.10	1.24	.11	1.24	.14	1.24	.16	1.23	.18	1.23	.21	1.23	.23

M.	11°		12°		13°		14°		15°		16°		17°		18°		19°		20°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0′	96.36	18.73	95.68	20.34	94.94	21.92	94.15	23.47	93.30	25.00	92.40	26.50	91.45	27.96	90.45	29.39	89.40	30.78	88.30	32.14
2	96.34	18.78	95.65	20.39	94.91	21.97	94.12	23.52	93.27	25.05	92.37	26.55	91.42	28.01	90.42	29.44	89.36	30.83	88.26	32.18
4	96.32	18.84	95.63	20.44	94.89	22.02	94.09	23.58	93.24	25.10	92.34	26.59	91.39	28.06	90.38	29.48	89.33	30.87	88.23	32.23
6	96.29	18.89	95.61	20.50	94.86	22.08	94.07	23.63	93.21	25.15	92.31	26.64	91.35	28.10	90.35	29.53	89.29	30.92	88.19	32.27
8	96.27	18.95	95.58	20.55	94.84	22.13	94.04	23.68	93.18	25.20	92.28	26.69	91.32	28.15	90.31	29.58	89.26	30.97	88.15	32.32
10	96.25	19.00	95.56	20.60	94.81	22.18	94.01	23.73	93.16	25.25	92.25	26.74	91.29	28.20	90.28	29.62	89.22	31.01	88.11	32.36
12	96.23	19.05	95.53	20.66	94.79	22.23	93.98	23.78	93.13	25.30	92.22	26.79	91.26	28.25	90.24	29.67	89.18	31.06	88.08	32.41
14	96.21	19.11	95.51	20.71	94.76	22.28	93.95	23.83	93.10	25.35	92.19	26.84	91.22	28.30	90.21	29.72	89.15	31.10	88.04	32.45
16	96.18	19.16	95.49	20.76	94.73	22.34	93.93	23.88	93.07	25.40	92.15	26.89	91.19	28.34	90.18	29.76	89.11	31.15	88.00	32.49
18	96.16	19.21	95.46	20.81	94.71	22.39	93.90	23.93	93.04	25.45	92.12	26.94	91.16	28.39	90.14	29.81	89.08	31.19	87.96	32.54
20	96.14	19.27	95.44	20.87	94.68	22.44	93.87	23.99	93.01	25.50	92.09	26.99	91.12	28.44	90.11	29.86	89.04	31.24	87.93	32.58
22	96.12	19.32	95.41	20.92	94.66	22.49	93.84	24.04	92.98	25.55	92.06	27.04	91.09	28.49	90.07	29.90	89.00	31.28	87.89	32.63
24	96.09	19.38	95.39	20.97	94.63	22.54	93.81	24.09	92.95	25.60	92.03	27.09	91.06	28.54	90.04	29.95	88.96	31.33	87.85	32.67
26	96.07	19.43	95.36	21.03	94.60	22.60	93.79	24.14	92.92	25.65	92.00	27.13	91.02	28.58	90.00	30.00	88.93	31.38	87.81	32.72
28	96.05	19.48	95.34	21.08	94.58	22.65	93.76	24.19	92.89	25.70	91.97	27.18	90.99	28.63	89.97	30.04	88.89	31.42	87.77	32.76
30	96.03	19.54	95.32	21.13	94.55	22.70	93.73	24.24	92.86	25.75	91.93	27.23	90.96	28.68	89.93	30.09	88.86	31.47	87.74	32.80
32	96.00	19.59	95.29	21.18	94.52	22.75	93.70	24.29	92.83	25.80	91.90	27.28	90.92	28.73	89.90	30.14	88.82	31.51	87.70	32.85
34	95.98	19.64	95.27	21.24	94.50	22.80	93.67	24.34	92.80	25.85	91.87	27.33	90.89	28.77	89.86	30.19	88.78	31.56	87.66	32.89
36	95.96	19.70	95.24	21.29	94.47	22.85	93.65	24.39	92.77	25.90	91.84	27.38	90.86	28.82	89.83	30.23	88.75	31.60	87.62	32.93
38	95.93	19.75	95.22	21.34	94.44	22.91	93.62	24.44	92.74	25.95	91.81	27.43	90.82	28.87	89.79	30.28	88.71	31.65	87.58	32.98
40	95.91	19.80	95.19	21.39	94.42	22.96	93.59	24.49	92.71	26.00	91.77	27.48	90.79	28.92	89.76	30.32	88.67	31.69	87.54	33.02
42	95.89	19.86	95.17	21.45	94.39	23.01	93.56	24.55	92.68	26.05	91.74	27.52	90.76	28.96	89.72	30.37	88.64	31.74	87.51	33.07
44	95.86	19.91	95.14	21.50	94.36	23.06	93.53	24.60	92.65	26.10	91.71	27.57	90.72	29.01	89.69	30.41	88.60	31.78	87.47	33.11
46	95.84	19.96	95.12	21.55	94.34	23.11	93.50	24.65	92.62	26.15	91.68	27.62	90.69	29.06	89.65	30.46	88.56	31.83	87.43	33.15
48	95.82	20.02	95.09	21.60	94.31	23.16	93.47	24.70	92.59	26.20	91.65	27.67	90.66	29.11	89.61	30.51	88.53	31.87	87.39	33.20
50	95.79	20.07	95.07	21.66	94.28	23.22	93.45	24.75	92.56	26.25	91.61	27.72	90.62	29.15	89.58	30.55	88.49	31.92	87.35	33.24
52	95.77	20.12	95.04	21.71	94.26	23.27	93.42	24.80	92.53	26.30	91.58	27.77	90.59	29.20	89.54	30.60	88.45	31.96	87.31	33.28
54	95.75	20.18	95.02	21.76	94.23	23.32	93.39	24.85	92.49	26.35	91.55	27.81	90.55	29.25	89.51	30.65	88.41	32.01	87.27	33.33
56	95.72	20.23	94.99	21.81	94.20	23.37	93.36	24.90	92.46	26.40	91.52	27.86	90.52	29.30	89.47	30.69	88.38	32.05	87.24	33.37
58	95.70	20.28	94.97	21.87	94.17	23.42	93.33	24.95	92.43	26.45	91.48	27.91	90.48	29.34	89.44	30.74	88.34	32.09	87.20	33.41
60	95.68	20.34	94.94	21.92	94.15	23.47	93.30	25.00	92.40	26.50	91.45	27.96	90.45	29.39	89.40	30.78	88.30	32.14	87.16	33.46
c = .75	.73	.15	.73	.16	.73	.17	.73	.19	.72	.20	.72	.21	.72	.23	.71	.24	.71	.25	.70	.26
c = 1.00	.98	.20	.98	.22	.97	.23	.97	.25	.96	.27	.86	.28	.95	.30	.95	.32	.94	.33	.94	.35
c = 1.25	1.22	.25	1.22	.27	1.21	.29	1.21	.31	1.20	.34	1.20	.35	1.19	.38	1.19	.40	1.18	.42	1.17	.44

M.	21°		22°		23°		24°		25°		26°		27°		28°		29°		30°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0′	87.16	33.46	85.97	34.73	84.73	35.97	83.46	37.16	82.14	38.30	80.78	39.40	79.39	40.45	77.96	41.45	76.50	42.40	75.00	43.30
2	87.12	33.50	85.93	34.77	84.69	36.01	83.41	37.20	82.09	38.34	80.74	39.44	79.34	40.49	77.91	41.48	76.45	42.43	74.95	43.33
4	87.08	33.54	85.89	34.82	84.65	36.05	83.37	37.23	82.05	38.38	80.69	39.47	79.30	40.52	77.86	41.52	76.40	42.46	74.90	43.36
6	87.04	33.59	85.85	34.86	84.61	36.09	83.33	37.27	82.01	38.41	80.65	39.51	79.25	40.55	77.81	41.55	76.35	42.49	74.85	43.39
8	87.00	33.63	85.80	34.90	84.57	36.13	83.28	37.31	81.96	38.45	80.60	39.54	79.20	40.59	77.77	41.58	76.30	42.53	74.80	43.42
10	86.96	33.67	85.76	34.94	84.52	36.17	83.24	37.35	81.92	38.49	80.55	39.58	79.15	40.62	77.72	41.61	76.25	42.56	74.75	43.45
12	86.92	33.72	85.72	34.98	84.48	36.21	83.20	37.39	81.87	38.53	80.51	39.61	79.11	40.66	77.67	41.65	76.20	42.59	74.70	43.47
14	86.88	33.76	85.68	35.02	84.44	36.25	83.15	37.43	81.83	38.56	80.46	39.65	79.06	40.69	77.62	41.68	76.15	42.62	74.65	43.50
16	86.84	33.80	85.64	35.07	84.40	36.29	83.11	37.47	81.78	38.60	80.41	39.69	79.01	40.72	77.57	41.71	76.10	42.65	74.60	43.53
18	86.80	33.84	85.60	35.11	84.35	36.33	83.07	37.51	81.74	38.64	80.37	39.72	78.96	40.76	77.52	41.74	76.05	42.68	74.55	43.56
20	86.77	33.89	85.56	35.15	84.31	36.37	83.02	37.54	81.69	38.67	80.32	39.76	78.92	40.79	77.48	41.77	76.00	42.71	74.49	43.59
22	86.73	33.93	85.52	35.19	84.27	36.41	82.98	37.58	81.65	38.71	80.28	39.79	78.87	40.82	77.42	41.81	75.95	42.74	74.44	43.62
24	86.69	33.97	85.48	35.23	84.23	36.45	82.93	37.62	81.60	38.75	80.23	39.83	78.82	40.86	77.38	41.84	75.90	42.77	74.39	43.65
26	86.65	34.01	85.44	35.27	84.18	36.49	82.89	37.66	81.56	38.78	80.18	39.86	78.77	40.89	77.33	41.87	75.85	42.80	74.34	43.67
28	86.61	34.06	85.40	35.31	84.14	36.53	82.85	37.70	81.51	38.82	80.14	39.90	78.73	40.92	77.28	41.90	75.80	42.83	74.29	43.70
30	86.57	34.10	85.36	35.36	84.10	36.57	82.80	37.74	81.47	38.86	80.09	39.93	78.68	40.96	77.23	41.93	75.75	42.86	74.24	43.73
32	86.53	34.14	85.31	35.40	84.06	36.61	82.76	37.77	81.42	38.89	80.04	39.97	78.63	40.99	77.18	41.97	75.70	42.89	74.19	43.76
34	86.49	34.18	85.27	35.44	84.01	36.65	82.72	37.81	81.38	38.93	80.00	40.00	78.58	41.02	77.13	42.00	75.65	42.92	74.14	43.79
36	86.45	34.23	85.23	35.48	83.97	36.69	82.67	37.85	81.33	38.97	79.95	40.04	78.54	41.06	77.09	42.03	75.60	42.95	74.09	43.82
38	86.41	34.27	85.19	35.52	83.93	36.73	82.63	37.89	81.28	39.00	79.90	40.07	78.49	41.09	77.04	42.06	75.55	42.98	74.04	43.84
40	86.37	34.31	85.15	35.56	83.89	36.77	82.58	37.93	81.24	39.04	79.86	40.11	78.44	41.12	76.99	42.09	75.50	43.01	73.99	43.87
42	86.33	34.35	85.11	35.60	83.84	36.80	82.54	37.96	81.19	39.08	79.81	40.14	78.39	41.16	76.94	42.12	75.45	43.04	73.93	43.90
44	86.29	34.40	85.07	35.64	83.80	36.84	82.49	38.00	81.15	39.11	79.76	40.18	78.34	41.19	76.89	42.15	75.40	43.07	73.88	43.93
46	86.25	34.44	85.02	35.68	83.76	36.88	82.45	38.04	81.10	39.15	79.72	40.21	78.30	41.22	76.84	42.19	75.35	43.10	73.83	43.95
48	86.21	34.48	84.98	35.72	83.72	36.92	82.41	38.08	81.06	39.18	79.67	40.24	78.25	41.26	76.79	42.22	75.30	43.13	73.78	43.98
50	86.17	34.52	84.94	35.76	83.67	36.96	82.36	38.11	81.01	39.22	79.62	40.28	78.20	41.29	76.74	42.25	75.25	43.16	73.73	44.01
52	86.13	34.57	84.90	35.80	83.63	37.00	82.32	38.15	80.97	39.26	79.58	40.31	78.15	41.32	76.69	42.28	75.20	43.18	73.68	44.04
54	86.09	34.61	84.86	35.85	83.59	37.04	82.27	38.19	80.92	39.29	79.53	40.35	78.10	41.35	76.64	42.31	75.15	43.21	73.63	44.07
56	86.05	34.65	84.82	35.89	83.54	37.08	82.23	38.23	80.87	39.33	79.48	40.38	78.06	41.39	76.59	42.34	75.10	43.24	73.58	44.09
58	86.01	34.69	84.77	35.93	83.50	37.12	82.18	38.26	80.83	39.36	79.44	40.42	78.01	41.42	76.55	42.37	75.05	43.27	73.52	44.12
60	85.97	34.73	84.73	35.97	83.46	37.16	82.14	38.30	80.78	39.40	79.39	40.45	77.96	41.45	76.50	42.40	75.00	43.30	73.47	44.15
c = .75	.70	.27	.69	.29	.69	.30	.68	.31	.68	.32	.67	.33	.66	.35	.66	.36	.65	.37	.65	.38
c = 1.00	.93	.37	.92	.38	.92	.40	.91	.41	.90	.43	.89	.45	.89	.46	.88	.48	.87	.49	.86	.51
c = 1.25	1.16	.46	1.15	.48	1.15	.50	1.14	.52	1.13	.54	1.12	.56	1.11	.58	1.10	.60	1.09	.62	1.08	.64

ELEMENTS OF MECHANICS.

Only the elements of machines are here treated, as all machinery, however complicated, is merely a combination of the six elementary forms, viz.: the *lever*, the *wheel and axle*, the *pulley*, the *inclined plane*, the *wedge*, and the *screw;* and these six can be still further reduced to the lever and the inclined plane. They are termed *mechanical powers*, but they do not produce force; they are only methods of applying and directing it.

The law of all mechanics is:

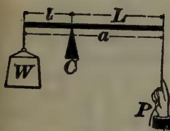
The power multiplied by the distance through which it moves is equal to the weight multiplied by the distance through which it moves.

Thus, 20 lb. of power moving through 5 ft. = 100 lb. of weight moving through 1 ft. In the following discussion friction is not considered, the idea being to give an elementary knowledge of the principles of the elements of mechanics.

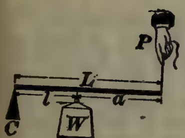
Levers.—There are three classes of levers. They are: (1) power at one end, weight at the other, and fulcrum between; (2) power at one end, fulcrum at the other, and weight between; (3) weight at one end, fulcrum at the other, and power between.

The handle of a blacksmith's bellows is a lever of the first class. The hand is the power and the bellows the weight, with the pivot between as the fulcrum. A crowbar as used for prying down top rock is a lever of the second class. The hand is the power, the rock to be barred down the weight, and the point in the roof against which the bar presses is the fulcrum. The treadle of a grindstone is a lever of the third class. The foot is the power, the hinge at the back of the foot is the fulcrum, and the moving of the machinery is the weight.

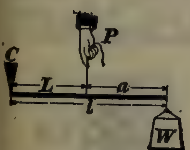
A lever is in equilibrium when the arms balance each other. The distances through which the power and the weight move depend on the comparative length of the arms. Let L represent power's distance from the fulcrum (C), l the weight's distance, and a the distance between power and weight; then, if L is twice l, the power will move twice as far as the weight. Substituting these terms in the law of mechanics, we have



$$P : W :: l : L. \quad PL = Wl.$$
$$P = \frac{Wl}{L}. \qquad W = \frac{PL}{l}.$$
$$l = \frac{Pa}{W+P}. \quad L = \frac{Wa}{W+P}.$$



$$P : W :: l : L. \quad PL = Wl.$$
$$P = \frac{Wl}{L}. \qquad W = \frac{PL}{l}.$$
$$L = \frac{Wa}{W-P}. \quad l = \frac{Pa}{W-P}.$$



$$P : W :: l : L. \quad PL = Wl.$$
$$P = \frac{Wl}{L}. \qquad W = \frac{PL}{l}.$$
$$L = \frac{Wa}{P-W}. \quad l = \frac{Pa}{P-W}.$$

In first- and second-class levers, as ordinarily used, we gain power and lose time; in the third class, we lose power and gain time.

EXAMPLE.—Having a weight of 2,000 lb. to lift with a lever, the short end of which is 2 ft. from the fulcrum and the long end 10 ft., how much power will be required?

$$L : l :: W : P, \text{ or } 10 : 2 :: 2{,}000 : 400 \text{ lb.}$$

The compound lever, Fig. 1, consists of several levers so constructed that the short arm of the first acts on the long arm of the second, and so on to the last.

If the distance from A to the fulcrum be four times the distance from the fulcrum to B, then a power of 5 lb. at A will lift 20 lb. at B. If the arms of the second lever are of the same comparative length, the 20-lb. power obtained at B will exert a pressure of 80 lb. on E; and if the third lever has the same comparative lengths, this 80 lb. at E will lift 320 lb. at G. Thus, a power of 5 lb. at A will balance a weight of 320 lb. at G. But, in order to raise the weight 1 ft., the power must pass through $\frac{320}{5}$, or 64 ft.

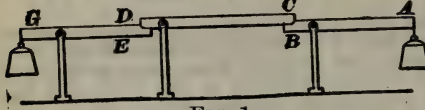


FIG. 1.

The **wheel and axle**, Fig. 2, is a modification of the lever. The ordinary windlass is a common form. The power is applied to the handle, the bucket is the weight, and the axis of the windlass is the fulcrum. The long arm of the lever is the handle, and the short arm is the radius of the axle. Thus, F is the fulcrum, Fc the long arm, and Fb the short arm. The wheel and axle has the advantage that it is a kind of perpetual lever. We are not obliged to prop up the weight and readjust the lever, but both arms work continuously.

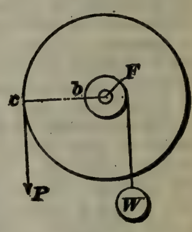


FIG. 2.

By turning the handle or wheel around once, the rope will be wound once around the axle, and the weight will be lifted that distance. Applying the law of mechanics, we have power × the circumference of the wheel = the weight × circumference of the axle; or, as the circumference of circles are proportional to their radii, we have

$$P : W :: r : R. \quad PR = Wr.$$

$$P = \frac{Wr}{R}. \quad R = \frac{Wr}{P}.$$

$$W = \frac{RP}{r}. \quad r = \frac{RP}{W}.$$

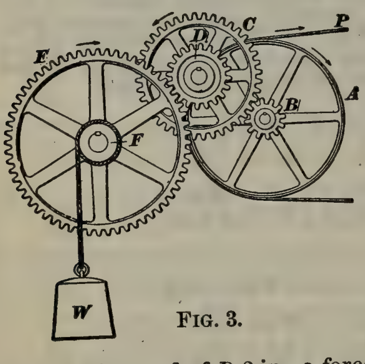


FIG. 3.

A **train**, Fig. 3, consists of a series of wheels and axles that act on one another on the principle of a compound lever. The *driver* is the wheel to which power is applied. The *driven*, or *follower*, is the one that receives motion from the *driver*. The *pinion* is the small gear-wheel on the axle.

If the diameter of the wheel A is 16 in., and of the pinion B 4 in., a pull of 1 lb. applied at P will exert a force of 4 lb. on the wheel C; if the diameter of C is 6 in., and of D 3 in., a force of 4 lb. on C will exert a force of 8 lb. on E. If E is 16 in. in diameter, and F 4 in., a force of 8 lb. on E will raise a weight of 32 lb. on F. In order, however, to lift this amount, according to the principle already named, the weight will only pass through $\frac{1}{32}$ of the distance of the power. Thus, power is gained and speed lost. To reverse this, we apply power to the axle, and, with a correspondingly heavy power, gain speed. Referring to Fig. 4, applying the law of mechanics,

$$P = \frac{Wrr'r''}{RR'R''}. \quad W = \frac{PRR'R''}{rr'r''}.$$

$$n : n'' :: r'r'' : RR'.$$

$$v : v' :: rr'r'' : RR'R''.$$

n, n', n'' = number of revolutions;
v, v' = velocity or speed of rotation;
r, r', r'', etc. = radii of the pinions;
R, R', R'', etc. = radii of the wheels.

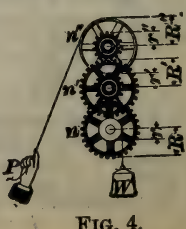


FIG. 4.

The Inclined Plane.—In Fig. 5 we see that the power must descend a distance equal to $A\,C$ in order to elevate the weight to the height $B\,C$; hence we have $P \times$ length of the inclined plane $= W \times$ the height of the inclined plane, or $P : W$: : height of inclined plane : length of inclined plane; or,

$$P = \frac{Wh}{l}.\quad W = \frac{Pl}{h} = \frac{P}{\sin a}.$$

To Find the Weight Required to Balance Any Weight on Any Inclined Plane. Multiply the given weight by the sine of the angle of inclination.

Thus, to find the weight required to balance a loaded car weighing 2,000 lb. on a plane pitching 18°, we multiply 2,000 by the sine of 18°, or $2{,}000 \times .3090170 = 618.034$ lb.

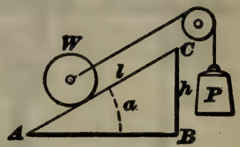


FIG. 5.

Or, if the length of the plane and the vertical height are given, multiply the load by the quotient of the vertical height divided by the length.

Thus, if a plane between two levels is 300 ft. long and rises 92.7 ft., and the load is 2,000 lb., the balancing weight is found as follows:

$$2{,}000 \times \frac{92.7}{300} = 618+.$$

CASE 1.—To find the horsepower required to hoist a given load up an inclined plane in a given time, use the formula

$$\frac{\left[\text{Load (in lb.)} + \text{weight of hoisting rope (in lb.)}\right] \times \left\{\begin{array}{l}\text{vertical height}\\ \text{through which the}\\ \text{load is raised (in ft.)}\end{array}\right\}}{33{,}000 \times \text{time of hoisting (in minutes)}}.$$

EXAMPLE.—Find the horsepower required to raise, in 3 minutes, a car weighing 1 ton and containing 1 ton of material up an inclined plane 1,000 ft. long and pitching 30°, if the rope weighs 1,500 lb.

The total load equals car + contents + rope $= 2{,}000 + 2{,}000 + 1{,}500 = 5{,}500$ lb.

The vertical height through which the load is hoisted equals

$$1{,}000 \times \sin 30° = 1{,}000 \times .5 = 500 \text{ ft.}$$

$$\therefore \text{ H. P.} = \frac{5{,}500 \times 500}{33{,}000 \times 3} = 27.7.$$

CASE 2.—When the power acts parallel to the base, use the formula

$W \times$ height of inclined plane $= P \times$ length of base.

These rules are theoretically correct, but in practice an allowance of about 30% must be made for friction and contingencies.

The **screw** consists of an inclined plane wound around a cylinder. The inclined plane forms the thread, and the cylinder, the body. It works in a nut that is fitted with reverse threads to move on the thread of the screw. The nut may run on the screw, or the screw in the nut. The power may be applied to either, as desired, by means of a wrench or a lever.

When the power is applied at the end of a lever, it describes a circle of which the lever is the radius r. The distance through which the power passes is the circumference of the circle; and the height to which the weight is lifted at each revolution of the screw is the distance between two of the threads, called the *pitch* (p). Therefore we have $P \times$ circumference of circle $= W \times$ pitch, or $P : W : : p : 2\,\pi\,r$.

$$P = \frac{Wp}{2\,\pi\,r}.\quad W = \frac{2\,\pi\,r\,P}{p}.$$

The power of the screw may be increased by lengthening the lever or by diminishing the distance between the threads.

EXAMPLE.—How great a weight can be raised by a force of 40 lb. applied at the end of a wrench 14 in. long, using a screw with 5 threads per inch?

$$W \times \tfrac{1}{5} = 40 \times 28 \times 3.1416.$$
$$W = 17{,}593 \text{ lb.}$$

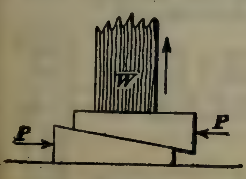


FIG. 6.

The **wedge** usually consists of two inclined planes placed back to back. (Fig. 6.) In theory, the same formula applies to the wedge as to the inclined plane, Case 2.

$P : W$: : thickness of wedge : length of wedge.

Friction, in the other mechanical powers, materially diminishes their efficiency; in this it is essential, since, without it, after each blow the wedge would fly back and the whole effect be lost. Again, in the others the power is applied as a steady force; in this it is a sudden blow, and is equal to the momentum of the hammer.

The **pulley** is simply another form of the lever that turns about a fixed axis or fulcrum. With a single fixed pulley shown in Fig. 7, there can be no gain of power or speed, as the force P must pull down as much as the weight W, and both move with the same velocity. It is simply a lever of the first class with equal arms, and is used to change the direction of the force.

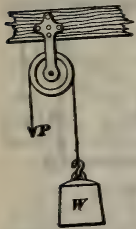


FIG. 7.

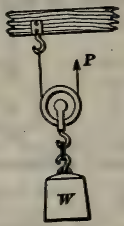


FIG. 8.

v = velocity of W. v' = velocity of P.

$$P = W. \quad v = v'.$$

Movable Pulley.—A form of the single pulley, where it moves with the weight, is shown in Fig. 8. In this, one half of the weight is sustained by the hook, and the other half by the power. Since the power is only one-half the weight, it must move through twice the space; in other words, by taking twice the time, we can lift twice as much. Here power is gained and time lost.

$$P = \tfrac{1}{2}\,W. \quad v' = 2\,v.$$

Combinations of Pulleys.—(1) In Fig. 9, we have the W sustained by three cords, each of which is stretched by a tension equal to the P, hence, 1 lb. of power will balance 3 lb. of weight. (2) In Fig. 10, a power of 1 lb. will in the

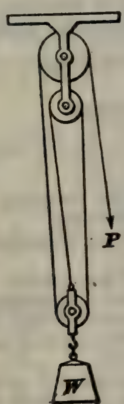


FIG. 9.

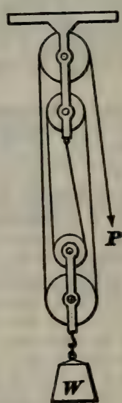


FIG. 10.

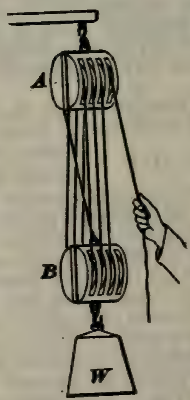


FIG. 11.

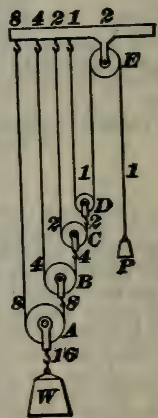


FIG. 12.

same manner sustain a W of 4 lb., and must descend 4 in. to raise the W 1 in. (3) Fig. 11 represents the ordinary tackle block used by mechanics, which can be calculated by the following general rule:

Rule.—*In any combination of pulleys where one continuous rope is used, a load on the free end will balance a weight on the movable block as many times as great as the load on the free end as there are parts of the rope supporting the load, not counting the free end.*

(4) In the cord marked *1, 1*, Fig. 12, each part has a tension equal to P; and in the cord marked *2, 2*, each part has a tension equal to $2\,P$, and so on with the other cords. The sum of the tensions acting on W is 16; hence, $W = 16\,P$. If n = number of pulleys,

$$P = \frac{W}{2^n}. \quad W = 2^n\,P.$$

Differential Pulley.—Fig. 13. $W = \dfrac{2\,P\,R}{R - r}.$

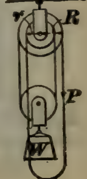


FIG. 13.

In all combinations of pulleys, nearly one-half the effective force is lost by friction.

Composition of Forces.—When two forces act on a body at different angles, their result may be obtained by the following rule:

Rule.—*Through a point draw two lines parallel to the directions of the lines of action of the two forces. With any convenient scale, measure off, from the point of intersection, distances corresponding to the magnitudes of the respective forces, and complete the parallelogram. From the common point of application, draw the diagonal of the parallelogram; this diagonal will be the resultant, and its magnitude can be measured with the same scale that was used to measure the two forces. When more than two forces act on a body simultaneously, find the resultant of any two of them as above; then, by the same method, combine this resultant with a third force, and this resultant with the fourth force, and so on.*

FRICTION AND LUBRICATION.

Friction.—Friction is the resistance to motion due to the contact of surfaces. It is of two kinds, *sliding* and *rolling*. If the surface of a body could be made perfectly smooth, there would be no friction; but, in spite of the most exact polish, the microscope reveals minute projections and cavities. We fill these with oil or grease, and thus diminish friction. Since no surface can be made perfectly smooth, some separation of the two bodies must, in all cases, take place in order to clear such projections as exist on the surfaces. Therefore, friction is always more or less affected by the amount of the perpendicular pressure that tends to keep them together.

The ultimate friction is the greatest frictional resistance that one body sliding over another is capable of opposing to any sliding force when at rest.

The *coefficient of friction* is the proportion that the ultimate friction in a given case bears to the perpendicular pressure. The coefficient of friction is usually expressed in decimals; but sometimes, as in the case of cars and engines, it is expressed in pounds (of friction) per ton.

The coefficient of friction equals the ultimate friction divided by the perpendicular pressure, and the ultimate friction equals the perpendicular pressure multiplied by the coefficient of friction. Thus, if we have a block weighing 100 lb. standing on another block, and it takes 35 lb. pressure to slide it, the coefficient of friction $= \frac{35}{100}$, or .35.

TABLE OF COEFFICIENTS OF FRICTION.

Materials.	Smooth, Clean, and Dry Plane Surfaces.	Smooth Plane Surfaces, Perfectly Lubricated With Tallow.
Oak on oak	.40	.079
Wrought iron on oak	.62	.085
Wrought iron on cast iron	.19	.103
Wrought iron on wrought iron	.14	.082
Wrought iron on brass	.17	.103
Cast iron on cast iron	.15	.100
Cast iron on brass	.15	.103
Steel on cast iron	.20	.105
Steel on steel	.14	
Steel on brass	.15	.056
Brass on cast iron	.22	.086
Brass on wrought iron	.16	.081
Brass on brass	.20	
Oak on cast iron		.080
Oak on wrought iron		.098
Cast iron on oak		.078
Steel on wrought iron		.093

The above coefficients are only approximate, for the coefficient will vary with the intensity of the pressure and the velocity, and also with the conditions of the atmosphere. But they are correct enough for practical purposes.

The friction of liquids moving in contact with solid bodies is independent of the pressure, because the forcing of the particles of the fluid over the projections on the surface of the solid body is aided by the pressure of the surrounding particles of the liquid, which tend to occupy the places of those forced over. Therefore, the coefficients of friction of liquids over solids do not correspond with those of solids over solids. The resistance is directly as the area of surface or contact.

COEFFICIENTS OF FRICTION IN AXLES.

Axle.	Bearing.	Ordinary Lubrication.	Lubricated Continuously.
Bell metal	Bell metal	.097	.049
Cast iron	Bell metal	.07	.05
Wrought iron	Bell metal	.07	.05
Wrought iron	Cast iron	.07	.05
Cast iron	Cast iron	.07	
Cast iron	Lignum vitæ	.10	
Wrought iron	Lignum vitæ	.12	

Friction naturally varies with the character of the surfaces, lubrication, and the nature of the lubricant. The best lubricants for the purposes should always be used, and the supply should be regular. When machinery is well lubricated, the lubricant keeps the surfaces apart, and the frictional resistance becomes very small, or about the same as the friction of liquids.

Frictional Resistance of Shafting.—

Let K = coefficient of friction;
W = work absorbed in foot-pounds;
P = weight of shafting and pulleys + the resultant stress of belts;
H = horsepower absorbed;
D = diameter of journal in inches;
R = number of revolutions per minute.

Then,

	ORDINARY OILING.	CONTINUOUS OILING.
$W =$	$.0182 \times P \times D$;	$.0112 \times P \times D$;
$H =$	$.000000556 \times P \times D \times R$;	$.000000339 \times P \times D \times R$;
$K =$	$.066$.	$.044$.

As a rough approximation, 100 ft. of shafting, 3 in. diameter, making 120 revolutions per minute, requires 1 horsepower.

For friction of air in mines, see "Coefficient of Friction," under Ventilation.

Friction of Mine Cars.—The friction of mine cars varies so much that it is impossible to give a formula for calculating it in every case. No two mine cars will show the same frictional resistance, when tested with a dynamometer, and, therefore, nothing but an average friction can be dealt with. The construction of the car, the condition of the track, and the lubrication are important factors in determining the amount of friction.

In this connection, we may, however, state some of the requisites of good oil box and journal bearings. Tightness is a prerequisite, and, in dry mines where the dust is very penetrating, this is especially important; the bearings should be sufficiently broad; the oil box large enough to hold sufficient oil to run a month without renewal, and so constructed that, while it may be quickly and easily opened, it will not open by jarring or by being accidentally struck by a sprag or a lump of coal.

There are a number of patented self-oiling wheels that are improvements on the old-style plain wheels, and each of these has undoubtedly some point of superiority over the old style.

Among the most extensively used of these patented wheels are those with annular oil chambers, and those with patent bushings. Their superiority consists in the fact that, if properly attended to, a well-lubricated bearing is secured with greater regularity and less work than when the old-style wheel was used.

With a view of adopting a standard wheel, the Susquehanna Coal Co., of Wilkesbarre, Pa., experimented for a number of years with different

styles of self-lubricating wheels, and as a result of the experiments it adopted a wheel patented by its chief engineer, Mr. Jas. H. Bowden.

Mr. R. Van A. Norris, E. M., Assistant Engineer, made a series of 989 tests with old-style wheels, some of which had patent removable bushings, and others annular oil chambers, and the Bowden wheel. The old wheels were found to be practically alike in regard to friction. All the wheels were of the loose outside type, 16 in. in diameter, mounted on $2\frac{1}{8}$ in. steel axles, with journals $5\frac{1}{4}$ in. long. The axles passed loosely through solid cast boxes, bolted to the bottom sills of the cars, and were not expected to revolve.

The table of friction tests shows the results obtained with both old- and new-style wheels, and is of interest to all colliery managers, inasmuch as the figures given for the old-style wheels alone are the most complete in existence, and, as stated before, they are good averages.

Tests were made on the starting and running friction of each style of wheel, under the conditions of empty and loaded cars, level and grade track, curves, and tangents. The instruments used were a Pennsylvania Railroad spring dynamometer, graduated to 3,000 lb., with a sliding recorder, a hydraulic gauge (not recording) reading to 10,000 lb., graduated to 25 lb., and a spring balance, capacity 300 lb., graduated to 3 lb. All these were tested and found correct previous to the experiments.

Most of the observations on single cars were made with the 300-lb. balance. The two types of "old-style" wheels have been classed together in the table. Each car was carefully oiled before testing, and several of each type were used, the results being averages from the number of trials shown in the table.

In the experiments on the slow start and motion, the cars were started very slowly by a block and tackle, and the reading was taken at the moment of starting. They were then kept just moving along the track for a considerable distance, and the average tractive force was noted, the whole constituting one experiment.

The track selected for these experiments was a perfectly straight and level piece of 42 in. gauge, about 200 ft. long, in rather better condition than the average mine track. The cars were $41\frac{3}{4}$ in. gauge, $3\frac{1}{2}$ ft. wheel base, 10 ft. long, capacity about 85 cu. ft., with 6-in. topping.

To ascertain the tractive force required at higher speeds, trips of one, four, and twenty cars, both empty and loaded, were attached to a mine locomotive and run about a mile for each test, the resistance at various points on the track, where its curve and grade were known, being noted, care also being taken to run at a constant speed. Unfortunately, only four of the "new-style" cars were available on the tracks where these trials were made.

The remarkably low results for the twenty-car trips are attributed to variations in the condition of the track, and the fact that the whole train was seldom pulling directly on the locomotive, the cars moving by jerks, so that correct observations were impracticable. The hydraulic gauge was used for these twenty-car tests, and the needle showed vibrations from 1 to 4 tons and back. The mean was taken as nearly as possible. The gauge was rather too quickly sensitive for the work, and the Pennsylvania Railroad dynamometer was not strong enough to stand the starting jerks and the strain of accelerating speed.

The tests marked "rope haul" were made on an empty-car haulage system, about 500 ft. long, with overhead endless rope running continuously at a speed of 180 ft. per min., the cars being attached to the moving rope by a chain, a ring at the end of which was slipped over a pin on the side of the car. The increase of friction on the heavier grades was due to the rope pulling at a greater angle across the car. Correction was not made for this angularity at the time, and the rope has since been rearranged, so that the correction cannot now be made. There were not enough curve experiments to permit the deduction of any general formula for the resistance of these cars on curves.

The experiments on grade agree fairly well with those on a level, the rather higher values obtained being probably due more to the greater effort required in moving them, and the consequent jerkiness of the motion, than to any real increase in resistance. As the experiments on all styles of wheels were made in an exactly similar manner, the comparative value of the results is believed to be nearly correct, the probable error in each set of experiments, as computed by the method of least squares, varying from about 4% for slow start and motion to 12% for the rapid motion and twenty-car trips.

SUMMARY OF FRICTION TESTS ON SUSQUEHANNA COAL CO.'S MINE CARS, APRIL, 1889.

DIMENSIONS OF WHEELS. 16 inches, diameter of tread. $2\frac{1}{8}$ inches, diameter of axle. $5\frac{1}{4}$ inches, length of journal.	OLD-STYLE WHEELS. Empty. Weight of Car.	Empty. Tractive Force per Car.	Empty. Tractive Force Due to Gravity.	Empty. Tractive Force per Car Due to Friction.	Empty. Tractive Force per Ton Due to Friction.	Empty. Percentage of Weight.	Loaded. Weight of Car.	Loaded. Tractive Force per Car.	Loaded. Tractive Force Due to Gravity.	Loaded. Tractive Force per Car Due to Friction.	Loaded. Tractive Force per Ton Due to Friction.	Loaded. Percentage of Weight.	No. of Tests. Empty.	No. of Tests. Loaded.
LEVEL.														
Average slow start	2,240	100		100	100	4.46	8,500	325		325	85	3.80	16	12
Average slow start	2,140	83		83	$86\frac{9}{10}$	3.88	7,885	357		357	$101\frac{4}{10}$	4.53	63	53
Average motion 50 ft. per min.	2,140	54		54	$56\frac{6}{10}$	2.52	7,885	205		205	$58\frac{3}{10}$	2.60	54	60
Average motion 1,000 ft. per min., 1 car	2,140	62		62	$64\frac{2}{10}$	2.89	7,885	262		262	$74\frac{4}{10}$	3.32	17	74
Average motion 1,000 ft. per min., 4 cars	2,240	$62\frac{1}{2}$		$62\frac{1}{2}$	$62\frac{1}{2}$	2.80							3	
Average motion 1,000 ft. per min., 20 cars	2,240	47		47	47	2.20	9,000	117		117	29	1.30	6	18
Average starting jerk, 20 cars	2,240	96		96	96	4.29	9,000	175		175	44	1.95	3	7
Average starting jerk, 2 cars, rope haul	2,240	630		630	630	28.12							10	
GRADE.														
Average slow start 12°	2,140	550	445	105	110	4.90	7,885	1,950	1,639	311	$88\frac{4}{10}$	3.94	2	2
Average motion 50 ft. per min., 12°	2,140	510	445	65	68	3.18	7,885	1,800	1,639	161	$45\frac{8}{10}$	2.00	10	16
Average motion 1,000 ft. per min., $1\frac{3}{4}$°, 1 car	2,140	125	65	60	$62\frac{8}{10}$	2.80							10	
Average motion 1,000 ft. per min., $1\frac{1}{2}$°, 1 car							7,885	425	205	220	$62\frac{5}{10}$	2.79		12
Average motion 200 ft. per min., rope haul, 2°	2,240	140	78	62	62	2.80	Cars pulled from side.						15	
Average motion 200 ft. per min., rope haul, 2° 30′	2,240	183	98	85	85	3.80							15	
Average motion 200 ft. per min., rope haul, 5° 10′	2,240	315	202	113	113	5.00							15	
Average motion 200 ft. per min., rope haul, 6° 10′	2,240	353	240	113	113	5.00							15	
CURVE.														
Average slow start, 85 ft. radius	2,240	125		125	125	5.58	8,500	400		400	106	4.70	10	10
Average slow start, 11 ft. radius, $1\frac{1}{2}$° grade							8,700	819	227	592	152	6.80		8
Average 20 cars, 1,000 ft. per min., 350 ft. radius	2,240	62		62	62	2.80	9,000	143		143	36	1.60	5	7
Average 20 cars, 1,000 ft. per min., 450 ft. radius	2,240	50		50	50	2.23	9,000	126		126	32	1.40	5	7
Average 4 cars, 1,000 ft. per min., 350 ft. radius	2,240	100		100	100	4.46							2	
Total number of tests													276	286

SUMMARY OF FRICTION TESTS ON SUSQUEHANNA COAL CO.'S MINE CARS, APRIL, 1889—(*Continued*).

Dimensions of Wheels. 16 inches, diameter of tread. $2\frac{1}{2}$ inches, diameter of axle. $5\frac{1}{4}$ inches, length of journal.	New-Style Wheels. Empty. Weight of Car.	Empty. Tractive Force per Car.	Empty. Tractive Force Due to Gravity.	Empty. Tractive Force per Car Due to Friction.	Empty. Tractive Force per Ton Due to Friction.	Empty. Percentage of Weight.	Loaded. Weight of Car.	Loaded. Tractive Force per Car.	Loaded. Tractive Force Due to Gravity.	Loaded. Tractive Force per Car Due to Friction.	Loaded. Tractive Force per Ton Due to Friction.	Loaded. Percentage of Weight.	No. of Tests. Empty.	No. of Tests. Loaded.
LEVEL.														
Average slow start	2,415	$66\frac{2}{3}$		$66\frac{2}{3}$	62	2.78	9,125	200		200	49	2.20	6	20
Average slow start	2,415	62		62	$55\frac{6}{10}$	2.48	8,160	193		193	53	2.36	82	48
Average motion 50 ft. per min.	2,415	40		40	$37\frac{1}{10}$	1.66	8,160	133		133	$36\frac{5}{10}$	1.63	81	72
Average motion 1,000 ft. per min., 1 car	2,415	$36\frac{2}{3}$		$36\frac{2}{3}$	$33\frac{9}{10}$	1.48	8,160	158		158	$43\frac{3}{10}$	1.93	6	39
Average motion 1,000 ft. per min., 4 cars	2,415	$37\frac{1}{2}$		$37\frac{1}{2}$	$34\frac{3}{4}$	1.56							6	
GRADE.														
Average slow start 12°	2,415	600	502	98	$90\frac{9}{10}$	4.06	8,160	2,000	1696	304	$83\frac{3}{10}$	3.73	2	2
Average motion 50 ft. per min., 12°	2,415	540	502	38	$35\frac{1}{10}$	1.56	8,160	1,825	1696	129	$35\frac{8}{10}$	1.58	6	12
Average motion 1,000 ft. per min., $1\frac{3}{4}$°, 1 car	2,415	100	73	27	25	1.12	8,160	400	249	151	$41\frac{5}{10}$	1.85	6	6
Average motion 1,000 ft. per min., $1\frac{1}{2}$°, 1 car							8,160	350	212	138	$37\frac{9}{10}$	1.69		16
CURVE.														
Average slow start, 85 ft. radius							9,125	275		275	67	3.00		8
Average slow start, 11 ft. radius, $1\frac{1}{2}$° grade							9,125	564	239	325	80	3.60		7
Average 4 cars, 1,000 ft. per min., 350 ft. radius	2,415	75		75	70	3.10							2	
												Total number of tests	197	230

Lubrication.—There is probably no factor that has a more direct bearing on the cost of production per ton of coal and ores than the lubrication of mine machinery, and yet it is doubtful if there is another item connected with the operation of a mine less understood by owners, their managers, and engineers in charge.

Steam plants are equipped with boilers of the highest known efficiency; heaters are used that, by utilizing waste steam, will heat the feedwater for boilers to the highest point. Modern engines that will develop a horsepower with the least amount of steam are installed; bends, instead of elbows, are placed in steam and exhaust pipes, so that the friction and back pressure may be reduced to a minimum. In a word, everything is done in the equipment of a plant to secure economy in its operation. After all this is done, frequently a long step is taken in the opposite direction by the use of an oil unsuited to the existing conditions, and those in charge of the plant are led to believe that the lubrication is all that could be desired, simply because the engines and machinery run quietly and the temperature of the bearings does not become alarmingly high. The office of a lubricant is not merely to secure this result, but, primarily, to reduce friction and wear to a minimum; and an oil that will do this is the best oil to use, no matter what the price per gallon may be.

Few realize the great loss in power due to the friction of wearing parts. One of the greatest living authorities on lubrication writes:

"It may probably be fairly estimated that one-half the power expended in the average case, whether in mill, mine, or workshop, is wasted on lost work, being consumed in overcoming the friction of lubricated surfaces."

He adds that a reduction of 50% in the work lost by friction has often been secured by a change of lubricants.

As one of many instances showing the loss that will occur by the use of inferior lubricants, attention is called to two flour mills located in one of the Middle States. One of the plants was equipped with a condensing engine capable of developing a horsepower on 24 lb. of water per hour; the other plant had a simple engine, taking 30 lb. of water per hour. The plant containing the condensing engine was purchased by the owner of the plant containing the simple engine. The new owner of the plant was surprised to learn that the cost of operation per barrel of flour manufactured was equally as great in the new plant as in the old one. The engines were indicated, and valves found to be properly adjusted and the engine working within the economical range, so far as load was concerned. The loss was then attributed to the boilers, but an evaporative test proved that there was no practical difference here, as the boilers, in both instances, were evaporating a fraction over 8 lb. of water per pound of coal. At this point, the question of lubrication was taken up, and, on the advice of an expert sent by a prominent manufacturer of lubricants to look over the plant, an entire change was made in the lubricants used, and, as a result, a money saving of over \$2.25 per day (practically \$700 per annum—this in a plant of less than 250 horsepower) was effected, notwithstanding the fact that the new lubricants used cost considerably more per gallon than those formerly used. This simply indicates that the price of an oil is of little importance in comparison with its friction-reducing power. Friction costs money, because it means greater cost of operation per unit of output.

Among the expenses chargeable to waste power, due to inferior lubrication, may be included: (1) The cost of power produced in excess of that really required to operate the mine per ton of output. In this calculation should be included the proper proportion of salaries of engineers, and all other items that contribute to the cost of the motive department, as well as the cost of mining the fuel consumed in producing this excess power. (2) Wear and tear of machinery, which is constantly doing more work per ton of coal mined than should be required of it.

There is also an element of danger that ought to receive serious consideration, as, while it is true that cylinder and bearing lubricants of indifferent merit will, under ordinary conditions, keep the cylinders from groaning and the bearings from becoming hot, experiments have proved that, in accomplishing such results, the oils in use were being taxed to their utmost; and there is record of many instances where, as a result of using oils of such limited endurance, accidents of a serious nature have occurred, necessarily causing shut-downs just at the time when the operation of a plant to its fullest capacity was imperative.

It is most difficult, in an article of this character, to do much more than

point out the danger due to the use of inferior lubricants, leaving it to the purchaser himself to determine as to the intrinsic worth of the lubricants offered to him. In making his selection he would do well to consult with and heed the advice of some highly responsible manufacturer of lubricants who has given to the question, in all its phases, the most careful study, and who would most probably have the benefit of a wide experience in the application as well as the manufacture of lubricants. Some buyers have, to their ultimate regret, adopted, as a method of determining the merits of lubricants, a schedule of laboratory tests. Such a method is not only useless, but it is misleading to any one other than a manufacturer of lubricants, who makes use of it merely as a means of insuring uniformity in his manufactured products, and not as a measure whereby to judge their practical value. Indeed, many oils can be very properly described by practically the same schedule of tests, and yet are widely apart when their utility for a given service is considered.

As a general guide in purchasing cylinder oil for mine lubrication, it might be said that a dark-colored oil is of greater value, as a rule, than one that has been filtered to a red or light amber color, as the process of filtration necessarily takes from the oil a considerable percentage of its lubricating value, and at the same time the process is an expensive one. In short, if a light-colored oil is insisted upon, a high price must be paid for an inferior lubricant. As a word of caution, however, it would be well to add right here that irresponsible manufacturers frequently take advantage of the fact that the most efficient and best known cylinder oils are dark-colored, and endeavor, with more or less success, to market as "cylinder oil" products absolutely unsuited to the lubrication of steam cylinders, and that would consequently be expensive could they be procured without cost.

For the lubrication of engine bearings, where modern appliances for feeding are used, an engine oil of a free running nature is best, as it more quickly reaches the parts requiring lubrication than an oil of a more sluggish nature. It, of course, must not be an oil susceptible to temperature changes, but must be capable of performing the service required of it under the most severe conditions, where an oil of less "backbone" would fail. Such an oil would also be suitable for the lubrication of dynamos, and should also give satisfaction where used in lubricating the cylinders of air compressors. Where the machinery is of an old type and loose-jointed, or when the bearings are open and the oil is applied directly to them by means of an oiler, an engine oil of a more sluggish, or viscid, nature is best.

Perhaps of equal importance to the lubrication of power machinery must be considered the lubrication of the axles of mine cars. This is important, first, because of the fact that perhaps three-fourths of the oil used about a coal mine is used for this purpose, and, secondly, because there is really a marked difference in the quality and, therefore, in the efficiency of lubricants used for this purpose. Fully nine-tenths of the prominent railroads of this country are today using car-axle oil, costing perhaps as much per gallon as much of the so-called cylinder oil that is used in coal mines, they having discovered, by exhaustive experiments, that the increased efficiency gained by using an oil of such quality many times offsets the difference in the cost per gallon and enables them to secure a greater mileage without any increase in their power or other fixed charges. This, we are certain, would apply just as forcibly to the lubrication of coal cars, no matter whether the power is derived from "long-eared mules" or electric motors, and we believe this feature of lubrication of mine equipment should receive more careful attention than it does receive, as a rule.

There is a considerable amount of waste in the lubrication of mine cars. This waste is hard to avoid, and, naturally, makes the buyer hesitate before adopting the use of a car oil that costs very much per gallon; but we believe it can be demonstrated, even in the face of this waste, that the increased efficiency secured by the use of a high-grade car oil would warrant its use. Such waste is pretty hard to correct in mines where the old-fashioned style of car axles is still in use, and where the oil is applied through an ordinary spout oil can into the axle box, and allowed to drip off the axles and on to the ground. When axles are equipped in the same manner as those of freight cars, or where cars are equipped with one of the several different styles of patent car wheels and axles that are coming into use quite extensively, it is possible to regulate the feeding of the oil to the axles, so as to reduce the waste to a minimum. One of these patent car wheels, which is perhaps better known than any other, is constructed with a hollow hub

that acts as a reservoir for the oil, the oil passing from this reservoir through small holes onto a felt washer, which it must saturate, and by which it is applied to the axles. Such wheels require a limpid oil, as a heavy, sluggish oil would not so readily saturate the felt washer referred to. A tight cap is adjusted to the end of the axle, to prevent waste of oil. These wheels will run quite a length of time without reoiling after the reservoir is once filled.

Of course, it costs something to equip mine cars with these patent axles, but we are convinced that such an outlay would result in more economical operation, particularly if at the same time the very best quality of car oil obtainable is used.

BEST LUBRICANTS FOR DIFFERENT PURPOSES (THURSTON).

Low temperatures, as in rock drills driven by compressed air	Light mineral lubricating oils.
Very great pressures, slow speed	Graphite, soapstone, and other solid lubricants.
Heavy pressures, with slow speed	The above, and lard, tallow, and other greases.
Heavy pressures and high speed	Sperm oil, castor oil, and heavy mineral oils.
Light pressures and high speed	Sperm, refined petroleum, olive, rape, cottonseed.
Ordinary machinery	Lard oil, tallow oil, heavy mineral oils, and the heavier vegetable oils.
Steam cylinders	Heavy mineral oils, lard, tallow.
Watches and other delicate mechanism.	Clarified sperm, neat's foot, porpoise, olive, and light mineral lubricating oils.

For mixture with mineral oils, sperm is best; lard is much used; olive and cottonseed are good.

STRENGTH AND WEIGHT OF MATERIALS

WOODEN BEAMS.

To Find the Quiescent Breaking Load of a Horizontal Square or Rectangular Beam Supported at Both Ends and Loaded at the Middle.—Multiply the breadth in inches by the square of depth in inches, divide the product by distance in feet between the supports, and multiply the quotient by the constant given in the table on the next page. Take safe working load one-third of breaking load.

To Find the Quiescent Breaking Load of a Horizontal Cylindrical Beam.—Divide the cube of the diameter in inches by the distance between the supports in feet, and multiply the quotient by the constant.

When the load is uniformly distributed on the beam, the results obtained by the above rules should be doubled.

EXAMPLE 1.—Find the quiescent breaking load and safe working load of a yellow-pine collar 8 in. square, 12 ft. between legs.

Breaking load $= \frac{8 \times 8^2}{12} \times 500 = 21{,}333$ lb. for seasoned, and 10,666 lb. for green timber.

Safe working load = 7,111 lb. for seasoned, and 3,556 lb. for green timber.

EXAMPLE 2.—Find the quiescent breaking load, and the safe working load of a hemlock collar 10 in. diameter, 7 ft. between legs.

Breaking load $= \frac{10^3}{7} \times 236 = 33{,}714$ lb. for seasoned timber, and $\frac{33{,}714}{2}$ = 16,857 lb. for green timber.

Safe working load $= \frac{33{,}714}{3} = 11{,}238$ lb. for seasoned, and $\frac{33{,}714}{6}$ or $\frac{11{,}238}{2}$ = 5,619 lb. for green timber.

To Find the Load a Rectangular Collar Will Support When Its Depth Is Increased. When the length and width remain constant, the load varies as the square of the depth.

EXAMPLE.—A rectangular collar 10 in. deep supports 15,000 lb. What will it support if its depth is increased to 12 in.?

$$10^2 : 12^2 :: 15{,}000 : 21{,}600. \quad \text{Ans.}$$

Having the Length and Diameter of a Collar, to Find the Diameter of a Longer Collar to Support the Same Weight.—For the same load, the strength of collars varies as the cubes of their diameters, and inversely as their lengths.

EXAMPLE.—If a collar 6 ft. long and 8 in. diameter supports a certain weight, what must be the diameter of a collar 12 ft. long to support the same weight?

$$\sqrt[3]{6} : \sqrt[3]{12} :: 8 \text{ in.} : 10+ \text{ in.} \quad \text{Ans.}$$

Having the Loads of Two Beams of Equal Length and the Diameter of One, to Find the Diameter of the Other.—When the lengths are equal, the diameters vary as the cube roots of the loads, or the cubes of the diameters vary as the loads.

EXAMPLE 1.—A beam 11 in. in diameter supports a load of 32,160 lb. What will be the diameter of another beam the same length, to support a load of 19,440 lb.?

$$\sqrt[3]{32{,}160} : \sqrt[3]{19{,}440} :: 11 : 9. \quad \text{Ans.}$$

EXAMPLE 2.—A beam 8 in. in diameter will support a load of 10,240 lb. What load will a beam the same length and 7 in. in diameter support?

$$8^3 : 7^3 :: 10{,}240 : 6{,}860. \quad \text{Ans.}$$

TABLE OF CONSTANTS.

Calculated for seasoned timber. For green timber, take one-half of these constants. Safe working load is one-third of breaking load.

Woods.	Square or Rectangular.	Round.	Woods.	Square or Rectangular.	Round.
Ash, white	650	383	Locust	600	353
Ash, swamp	400	236	Lignum vitæ	650	383
Ash, black	300	177	Larch	400	236
Balsam, Canada	350	206	Maple	550	324
Beech, white	450	265	Oak, red or black	550	324
Beech, red	550	324	Oak, white	600	353
Birch, black	450	265	Oak, live	600	353
Birch, yellow	450	266	Pine, white	450	265
Cedar, white	250	147	Pine, yellow	500	295
Chestnut	450	265	Pine, pitch	550	324
Elm	350	206	Poplar	550	324
Elm, rock	600	353	Spruce	450	265
Hemlock	400	236	Sycamore	500	295
Hickory	650	383	Willow	350	206
Ironwood	600	353			

To Find the Diameter of a Collar When the Weight Increases in Proportion to the Length.—Find the required diameter to support the same weight as the short collar. Then the length of the short collar is to the length of the long one as the diameter found to support the original weight is to the required diameter.

EXAMPLE.—If a collar 6 ft. long, 8 in. in diameter, supports a certain weight, what must be the diameter of a collar 12 ft. long to support twice the weight?

$$1 : 2 :: \frac{8^3}{6} : \frac{(\quad)^3}{12}, \text{ or } 1 : 2 :: 2 \times 8^3 : (\quad)^3,$$

or

$$\sqrt[3]{1} : \sqrt[3]{2} :: 8\sqrt[3]{2} : (\quad) = 12.7. \quad \text{Ans.}$$

IRON AND STEEL BEAMS.

Constants for use in calculating strength of iron and steel beams:

Cast iron	2,000
Wrought iron	2,200
Steel	5,000

Safe Loads Uniformly Distributed for Standard and Special I Beams.

(Tons of 2,000 Pounds.)

Distance Between Supports in Feet.	12″ I. 40 Lb. Special.	12″ I. 31.5 Lb.	Add for Every Lb. Increase in Weight.	10″ I. 25 Lb.	Add for Every Lb. Increase in Weight.	9″ I. 21 Lb.	Add for Every Lb. Increase in Weight.
12	19.92	15.99	.26	10.85	.22	8.39	.20
13	18.39	14.76	.24	10.02	.20	7.74	.18
14	17.08	13.70	.23	9.30	.19	7.19	.17
15	15.94	12.79	.21	8.68	.17	6.71	.16
16	14.94	11.99	.20	8.14	.16	6.29	.15
17	14.06	11.29	.19	7.66	.15	5.92	.14
18	13.28	10.66	.18	7.24	.14	5.59	.13
19	12.58	10.10	.17	6.86	.14	5.30	.12
20	11.95	9.59	.16	6.51	.13	5.03	.12
21	11.38	9.14	.15	6.20	.12	4.79	.11
22	10.87	8.72	.14	5.92	.12	4.58	.11
23	10.39	8.34	.14	5.66	.11	4.38	.10
24	9.96	7.99	.13	5.43	.11	4.19	.10
25	9.56	7.67	.13	5.21	.10	4.03	.09
26	9.19	7.38	.12	5.01	.10	3.87	.09
27	8.85	7.11	.12	4.32	.10	3.73	.09
28	8.54	6.85	.11	4.65	.09	3.59	.08
29	8.24	6.62	.11	4.49	.09	3.47	.08
30	7.97	6.40	.11	4.34	.09	3.36	.08

Distance Between Supports in Feet.	8″ I. 18 Lb.	Add for Every Lb. Increase in Weight.	7″ I. 15 Lb.	Add for Every Lb. Increase in Weight.	6″ I. 12.25 Lb.	Add for Every Lb. Increase in Weight.	5″ I. 9.75 Lb.	Add for Every Lb. Increase in Weight.	4″ I. 7.5 Lb.	Add for Every Lb. Increase in Weight.	3″ I. 5.5 Lb.	Add for Every Lb. Increase in Weight.
5	15.17	.42	11.04	.36	7.75	.31	5.16	.26	3.18	.21	1.76	.16
6	12.64	.35	9.20	.30	6.46	.26	4.30	.22	2.65	.18	1.47	.13
7	10.84	.30	7.89	.26	5.54	.22	3.69	.19	2.27	.15	1.26	.11
8	9.48	.26	6.90	.23	4.84	.19	3.23	.16	1.99	.13	1.10	.10
9	8.43	.23	6.13	.20	4.31	.17	2.87	.14	1.77	.12	0.98	.09
10	7.59	.21	5.52	.18	3.88	.16	2.58	.13	1.59	.11	0.88	.08
11	6.90	.19	5.02	.16	3.52	.14	2.35	.12	1.45	.10	0.80	.07
12	6.32	.18	4.60	.15	3.23	.13	2.15	.11	1.33	.09	0.73	.07
13	5.83	.16	4.25	.14	2.98	.12	1.98	.10	1.22	.08	0.68	.06
14	5.42	.15	3.94	.13	2.77	.11	1.84	.09	1.14	.08	0.63	.06
15	5.06	.14	3.68	.12	2.58	.10	1.72	.09	1.06	.07	0.59	.05
16	4.74	.13	3.45	.11	2.42	.10	1.61	.08	0.99	.07	0.55	.05
17	4.46	.12	3.25	.11	2.28	.09	1.52	.08	0.94	.06	0.52	.05
18	4.21	.12	3.07	.10	2.15	.09	1.43	.07	0.88	.06	0.49	.04
19	3.99	.11	2.91	.09	2.04	.08	1.36	.07	0.84	.06	0.46	.04
20	3.79	.11	2.76	.09	1.94	.08	1.29	.07	0.80	.05	0.44	.04
21	3.61	.10	2.63	.09	1.85	.07	1.23	.06	0.76	.05	0.42	.04

Safe loads given include weight of beam. Maximum fiber stress, 16,000 lb. per sq. in.
For spacings below the heavy lines, the deflections will be greater than the allowable limit for plastered ceilings, equaling $\frac{1}{360}$ span.

Hard steel will break the same as cast iron. Soft steel will bend like wrought iron. The elastic limit of wrought iron is reached at about 2,200 lb. As it does not break, we use the limit of elasticity.

To Find the Quiescent Breaking Load of a Horizontal Square or Rectangular Iron or Steel Beam Supported at Both Ends and Loaded at the Middle.—Multiply the square of its depth in inches by its breadth in inches; multiply this result by the constant for the material used, and divide by the length in feet between the supports. For the neat load, subtract one-half the weight of the beam.

To Find the Quiescent Breaking Load of a Cylindrical Iron or Steel Beam. Find the breaking load of a square beam the sides of which are equal to the diameter of the round one, and multiply by .6.

Safe working load in each of the preceding cases is one-third of the breaking load. If the load is equally distributed over the beam, it will be twice as great.

PILLARS OR PROPS.

To Find the Crushing Load of Either Square or Rectangular Wooden Pillars or Props.—Call one side of the square or the least side of the rectangle the breadth. Divide the square of the length in inches by the square of the breadth in inches, multiply the quotient by .004, add 1 to the product, and divide the constant in the following table by the result. Then multiply this quotient by the number of square inches in the end of the prop.

$$\text{Or, breaking load in lb.} = \frac{\text{Constant}}{\left(\frac{l^2}{b^2} \times .004\right) + 1} \times b\,d,$$

when l = length in inches, b = breadth in inches, and d = depth in inches.

CRUSHING LOADS OF WELL-SEASONED AMERICAN WOODS.

Wood.	Crushing Load. Lb. per Sq. In.	Wood.	Crushing Load. Lb. per. Sq. In.
Ash	6,800	Maple, sugar, black	8,000
Beech	7,000	Maple, white, red	6,800
Birch	8,000	Oak, white, red, black	7,000
Cedar, red	6,000	Oak, scrub, basket	6,000
Cedar, white	4,400	Oak, chestnut, live	7,500
Chestnut	5,300	Oak, pin	6,500
Hemlock	5,300	Pine, white	5,400
Hickory	8,000	Pine, pitch	5,000
Linden	5,000	Pine, Georgia	8,500
Locust, black, yellow	9,800	Poplar	5,000
Locust, honey	7,000	Spruce, black	5,700
Maple, broad-leafed Oregon	5,300	Spruce, white	4,500
		Willow	4,400

For green timber, take one-half of the constants or crushing strength. Safe working load equals one-third of crushing load.

EXAMPLE.—What is the breaking load of a well-seasoned hemlock post 10 in. by 8 in. and 12 ft. long?

$5{,}300 \div \left[1 + \left(\frac{144^2}{8^2} \times .004\right)\right] = 2{,}308.4$ lb. per sq. in. of area. $2{,}308.4 \times 80 = 184{,}672$ lb. Ans.

To Find the Breaking Load of a Cylindrical Wooden Prop.—Find the breaking load of a square prop whose ends are equal in area to those of the cylindrical one, and proceed according to foregoing rule.

EXAMPLE.—What is the safe working load for a hemlock mine prop 10 in. diameter, 10 ft. long?

The area of the end of the prop = 78.54 sq. in. A square of equal area will have sides equal to $\sqrt{78.54} = 8.86+$ in.

Then, $5{,}300 \div \left[1 + \left(\frac{120^2}{8.86^2} \times .004\right)\right] = 3{,}058.3$ lb. per each sq. in. of area.

And $3,058.3 \times 78.54 = 240,198$ lb. This is the crushing strength of a similar prop of seasoned timber, but, as mine timber is used in its green state, we take one-half of 240,198 lb., or 120,099 lb., as the crushing load of the prop in question. Then, the safe working load is one-third of this, or 40,033 lb.

The strength of similar props varies as the cubes of their diameters, and inversely as their lengths.

SAFE LOADS, IN TONS OF 2,000 POUNDS, FOR HOLLOW CYLINDRICAL CAST-IRON COLUMNS.

(*The Carnegie Steel Co., Limited.*)

Outside Diam. Inches.	Thickness of Metal.	Length of Columns in Ft.									Sectional Area. Inches.	Weight in Lb. of Columns per Ft. of Length.
		8	10	12	14	16	18	20	22	24		
		Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.		
6	½	26.2	23.0	20.1	17.5	15.2	13.2	11.5			8.6	26.95
6	¾	37.5	33.0	28.8	25.0	21.7	18.9	16.5			12.4	38.59
6	⅞	42.7	37.6	32.8	28.5	24.7	21.5	18.8			14.1	43.96
6	1	47.6	41.9	36.5	31.8	27.6	24.0	21.0			15.7	49.01
6	1⅛	52.2	46.0	40.1	34.8	30.2	26.3	23.0			17.2	53.76
7	¾	47.7	43.1	38.5	34.3	30.4	26.9	23.9	21.2	18.9	14.7	45.96
7	1	61.1	55.2	49.3	43.8	38.9	34.4	30.6	27.1	24.2	18.9	58.90
7	1⅛	67.2	60.8	54.3	48.3	42.8	37.9	33.7	29.9	26.7	20.8	64.77
8	¾	57.9	53.3	48.6	44.1	39.7	35.8	32.2	28.9	26.1	17.1	53.29
8	1	74.6	68.7	62.5	56.7	51.1	46.0	41.4	37.3	33.6	22.0	68.64
8	1¼	89.9	82.8	75.5	68.4	61.7	55.5	49.9	44.9	40.5	26.5	82.71
9	¾	68.1	63.6	58.9	54.2	49.6	45.2	41.2	37.5	34.1	19.4	60.65
9	1	88.0	82.3	76.2	70.0	64.1	58.4	53.2	48.4	44.1	25.1	78.40
9	1¼	106.6	99.6	92.2	84.8	77.6	70.8	64.4	58.7	53.4	30.4	94.94
9	1½	123.8	115.7	107.1	98.5	90.1	82.2	74.8	68.1	62.0	35.3	110.26
9	1¾	139.6	130.5	120.8	111.1	101.6	92.7	84.4	76.8	69.9	39.9	124.36
10	1	101.4	95.9	89.8	83.6	77.4	71.5	65.8	60.5	55.5	28.3	88.23
10	1¼	123.3	116.5	109.1	101.6	94.1	86.8	79.9	73.4	67.5	34.4	107.23
10	1½	143.7	135.8	127.3	118.5	109.7	101.2	93.2	85.6	78.7	40.1	124.99
10	1¾	162.7	153.8	144.1	134.1	124.2	114.6	105.5	97.0	89.1	45.4	141.65
11	1	114.8	109.4	103.5	97.3	91.0	84.8	80.2	73.1	67.7	31.4	98.03
11	1¼	139.9	133.3	126.1	118.6	110.9	103.3	97.8	89.4	82.5	38.3	119.46
11	1½	163.5	155.9	147.5	138.6	128.7	120.8	114.3	104.1	96.4	44.8	139.68
11	1¾	185.7	177.1	167.5	157.5	147.3	137.2	129.8	118.3	109.5	50.9	158.68
11	2	206.6	196.9	186.3	175.1	163.8	152.6	144.4	131.5	121.8	56.6	176.44
12	1	128.0	122.9	117.2	111.0	104.7	98.4	92.2	86.1	80.4	34.6	107.51
12	1¼	156.4	150.1	143.1	135.7	127.9	120.2	112.6	105.2	98.2	42.2	131.41
12	1½	183.3	175.9	167.7	159.0	149.9	140.9	132.0	123.3	115.1	49.5	154.10
12	1¾	208.7	200.4	191.0	181.1	170.7	160.4	150.3	140.5	131.1	56.4	175.53
12	2	232.7	223.4	213.0	201.9	190.4	178.9	167.6	156.6	146.1	62.8	195.75
13	1	141.2	136.3	130.7	124.7	118.5	112.1	105.8	99.5	93.5	37.7	117.53
13	1¼	172.8	166.8	160.0	152.7	145.0	137.2	129.4	121.8	114.4	46.1	143.86
13	1½	203.0	195.9	187.9	179.3	170.3	161.1	152.0	143.1	134.3	54.2	168.98
13	1¾	231.6	223.6	214.5	204.7	194.4	183.9	173.5	163.3	153.3	61.9	192.88
13	2	258.9	249.9	239.7	228.7	217.3	205.5	193.9	182.5	171.3	69.1	215.56
14	1	154.3	149.6	144.3	138.5	132.3	125.9	119.5	113.1	106.8	40.8	127.60
14	1¼	189.2	183.4	176.9	169.7	162.2	154.4	146.5	138.6	131.0	50.1	156.31
14	1½	222.6	215.8	208.1	199.7	190.8	181.7	172.3	163.1	154.1	58.9	183.67
14	1¾	254.4	246.7	237.9	228.3	218.1	207.6	197.0	186.5	176.2	67.4	210.00
14	2	284.8	276.2	266.4	255.6	244.2	232.4	220.6	208.8	197.2	75.4	235.12
15	1	167.4	162.9	157.8	152.1	146.0	139.7	133.3	126.8	120.4	44.0	137.28
15	1¼	205.5	200.0	193.7	186.7	179.3	171.5	163.6	155.7	147.9	54.0	168.48
15	1½	242.1	235.7	228.2	220.0	211.2	202.1	192.8	183.5	174.2	63.6	198.74
15	1¾	277.2	269.8	261.3	251.9	241.9	231.4	220.7	210.1	199.5	72.9	227.45
15	2	310.8	302.5	293.0	282.5	271.2	259.5	247.5	235.5	223.6	81.7	254.90

MINIMUM SAFE-BEARING VALUES OF MASONRY MATERIALS.

Materials.	Tons per Sq. Ft.
Granite, capstone	50
Squared masonry	25
Sandstone, capstone	25
Squared masonry	12
Rubble, laid in lime mortar	5
Rubble, laid in cement mortar	10
Limestone, capstone	36
Squared masonry	18
Rubble, laid in lime mortar	5
Rubble, laid in cement mortar	10
Bricks, hard, laid in lime mortar	7
Hard, laid in Portland cement mortar	14
Hard, laid in Rosendale cement mortar	10
Concrete, 1 Portland, 2 sand, 5 broken stone	10

SPECIFIC GRAVITY, WEIGHT, AND PROPERTIES OF MATERIALS, ETC.

The specific gravity of a body is the ratio of its weight to the weight of an equal bulk of pure water, at a standard temperature (62° F. = 16.670° C.).

Some experimenters have used 60° F. as the standard temperature, others 32° and still others, 39.1°. To reduce a specific gravity, referred to water at 39.1° F., to the standard of water at 62° F., multiply by 1.00112.

Given specific gravity referred to water at 62° F., multiply by 62.355 to find the weight of a cubic foot of the substance. Given weight per cubic foot, to find specific gravity, multiply by 0.016037.

Given specific gravity, to find the weight per cubic inch, multiply by 0.036085.

To Find the Specific Gravity of a Solid Heavier Than Water.—Weigh the body both in air and in water, and divide the weight in air by the difference of the weights in air and water.

EXAMPLE.—A piece of coal weighs, say, 480 grains. Loss of weight when weighed in water, 398 grains.

Then, $\frac{480}{398} = 1.206$, specific gravity of the coal compared with water at 1,000.

As a cubic foot of water weighs, approximately, 1,000 oz., the weight of a cubic foot of any substance can be found by multiplying its specific gravity by 1,000.

To Find the Specific Gravity of a Solid Lighter Than Water.—Attach to it another body heavy enough to sink it; weigh severally the compound mass and the heavier body in water, divide the weight of the body in air by the weight of the body in air plus the weight of the sinker in water minus the combined weight of the sinker and body in water.

To Find the Specific Gravity of a Fluid.—Weigh both in and out of the fluid a solid (insoluble) of known specific gravity, and divide the product of the weight lost in the fluid and the specific gravity of the solid by the weight of the solid.

The weight of a cubic foot of water at a temperature of 62° is about 1,000 oz. avoirdupois, and the specific gravity of a body, water being 1,000, shows the weight of a cubic foot of that body in ounces avoirdupois. Then, if the magnitude of the body be known, its weight can be computed; or, if its weight be known, its magnitude can be calculated, provided we know its specific gravity; or, of the magnitude, weight, and specific gravity, any two being known, the third may be found.

To Find the Magnitude of a Body in Cubic Feet From its Weight.—Divide the weight of the body in ounces by 1,000 times the specific gravity of the body.

To Find the Weight of a Body in Ounces From Its Magnitude.—Divide the weight of the body in ounces by the specific gravity of the substance multiplied by 1,000.

NOTE.—The specific gravity of any substance is equal to its weight in grams per cubic centimeter. (See table of metric weights and measures.)

SPECIFIC GRAVITY OF SUBSTANCES.

Substance.	Average Specific Gravity.	Average Weight per Cu. Ft. Lb.
Air, atmospheric; at 60° F. under pressure of 1 atmosphere, or 14.7 lb. per sq. in.	.00123	.0765
Alcohol, pure	.793	49.43
Alcohol, of commerce	.834	52.1
Aluminum	2.66	166.0
Anthracite* coal	1.5	93.5
Asphaltum	1.4	87.3
Brass, cast	8.1	504.0
Brass, rolled	8.4	524.0
Bronze, gun metal	8.5	529.0
Brick, best pressed		150.0
Brick, common hard		125.0
Carbonic-acid gas	.00187	.1167
Clay, dry, in lumps, loose		63.0
Clay, potters', dry	1.9	119.0
Coke,† loose, of good coal		27.5
Coal, bituminous ‡	1.35	84.0
Coal, bituminous, broken loose		50.0
Coal, bituminous, moderately shaken		54.0
Copper, cast	8.7	542.0
Copper, rolled	8.9	555.0
Cork	.25	15.6
Earth, common loam, perfectly dry, loose		76.0
Earth, common loam, perfectly dry, shaken		87.0
Earth, common loam, perfectly dry, moderately packed		95.0
Earth, common loam, slightly moist, loose		78.0
Earth, common loam, more moist, loose		80.0
Earth, common loam, more moist, shaken		90.0
Earth, common loam, more moist, packed		96.0
Earth, common loam, as a soft flowing mud		108.0
Earth, common loam, as a soft mud packed		115.0
Gold, cast, pure or 24 carat	19.26	1,204.0
Gravel		98.0
Gutta percha	.98	61.1
Gypsum (plaster of Paris)	2.27	141.6
Gypsum, in irregular lumps		82.0
Gypsum, ground, loose		56.0
Gypsum, ground, well shaken		64.0
Gypsum, calcined, loose		56.0
Hydrogen gas, 14½ times lighter than air and 16 times lighter than oxygen		.00527
Ice	.92	57.4
Iron, cast	7.21	450.0
Iron, rolled bars	7.65	480.0
Iron, sheet		485.0
Iron, wrought	7.77	485.0
Lead	11.38	709.6
Lime, quick	1.5	95.0
Lime, quick, ground, loose, per struck bushel, 66 lb.		53.0
Mercury, at 32° F.	13.62	849.0
Mercury, at 60° F.	13.58	846.0
Mercury, at 212° F.	13.38	836.0
Nitrogen gas, $\frac{1}{14}$ part lighter than air		.0744
Oils, whale, olive	.92	57.3

* Anthracite increases about 75 per cent. in bulk when broken to any market size. A ton loose, averages from 40 to 43 cu. ft.

† A heaped bushel, loose, weighs from 35 to 42 lb. A ton occupies 80 to 97 cu. ft.

‡ A heaped bushel, loose, weighs about 74 lb., and a ton occupies from 43 to 48 cu. ft. Bituminous coal, when broken, occupies 75 per cent. more space than in the solid.

SPECIFIC GRAVITY OF SUBSTANCES—(*Continued*).

Substance.	Average Specific Gravity.	Average Weight per Cu. Ft. Lb.
Oxygen gas, $\frac{1}{10}$ part heavier than air	.00136	.0846
Petroleum	.878	54.8
Powder	1.5–1.85	105.0
Rosin	1.1	68.6
Silver	10.5	655.0
Slate	2.8	175.0
Steel	7.85	490.0
Sulphur	2.0	125.0
Tallow	.94	58.6
Tin, cast	7.35	459.0
Water, pure, rain or distilled, at 32° F., Barom. 30 in.		62.417
Water, pure, rain or distilled, at 62° F., Barom. 30 in.	1.00	62.355
Water, pure, rain or distilled, at 212° F., Barom. 30 in.		59.7
Water, sea, average	1.028	64.08
Zinc	7.00	437.5

The following table gives the specific gravities of various coals:

Name of Coal.	Sp. Gr.	Weight of a Cu. Ft. Lb.	Weight of a Cu. Yd. Tons.
Newcastle Hartley, England	1.29	80.6	.972
Wigan, 4 ft., England	1.20	75.0	.914
Portland, England	1.30	81.2	.978
Anthracite, Wales	1.39	86.9	1.047
Eglington, Scotland	1.25	78.1	.941
Anthracite, Irish	1.59	99.4	1.193
Anthracite, Pennsylvania	1.55	96.9	1.167
Bituminous, Pennsylvania	1.40	87.5	1.054
Block coal, Indiana	1.27	79.4	.956

SPECIFIC GRAVITY AND WEIGHT OF PREPARED ANTHRACITE COAL.

To Mr. Irving A. Stearns, General Superintendent of the Pennsylvania Railroad Co.'s Coal Department, we are indebted for the following summary of tests made by the mining engineers of the company.

In a series of tests to ascertain the specific gravity of the coal from different seams worked by the company, it was found that the average specific gravity was 1.4784, and the average weight per cubic foot was 92.50 lb. This was calculated for space filled at breaker without settling. Add 5% for packed spaces of large heaps.

WEIGHT PER CUBIC FOOT OF SUSQUEHANNA COAL CO.'S WHITE ASH ANTHRACITE COAL.

Size.	Size of Mesh.		Weight per Cu. Ft. Pounds.	Cu. Ft. From 1 Cu. Ft. Solid.
	Over.	Through.		
Lump	$4\frac{1}{2}''$ to $9''$		57	1.614
Broken	$2\frac{3}{8}''$ to $2\frac{7}{8}''$	$3\frac{1}{4}''$ to $4\frac{1}{2}''$	53	1.755
Egg	$1\frac{3}{4}''$ to $2\frac{1}{4}''$	$2\frac{3}{8}''$ to $2\frac{7}{8}''$	52	1.769
Large stove	$1\frac{1}{4}''$ to $1\frac{7}{8}''$	$1\frac{3}{4}''$ to $2\frac{1}{4}''$	$51\frac{1}{2}$	1.787
Small stove	$1''$ to $1\frac{1}{4}''$	$1\frac{1}{4}''$ to $1\frac{1}{2}''$	$51\frac{1}{4}$	1.795
Chestnut	$\frac{5}{8}''$ to $\frac{3}{4}''$	$1''$ to $1\frac{1}{4}''$	51	1.804
Pea	$\frac{3}{8}''$ to $\frac{5}{8}''$	$\frac{5}{8}''$ to $\frac{7}{8}''$	$50\frac{3}{4}$	1.813
No. 1 buckwheat	$\frac{3}{16}''$ to $\frac{3}{8}''$	$\frac{3}{8}''$ to $\frac{5}{8}''$	$50\frac{3}{4}$	1.813
No. 2 buckwheat		$\frac{3}{16}''$ to $\frac{3}{8}''$	$50\frac{3}{4}$	1.813

LINE SHAFTING.

Shafting is usually made cylindrically true, either by a special rolling process, when it is known as **cold-rolled shafting,** or it is turned up in a machine called a *lathe.* In the latter case, it is called **bright shafting.** What is known as **black shafting** is simply bar iron rolled by the ordinary process and turned where it receives the couplings, pulleys, bearings, etc.

Bright turned shafting varies in diameter by $\frac{1}{4}$ in. up to about $3\frac{1}{2}$ in. in diameter; above this diameter the shafting varies by $\frac{1}{2}$ in. The actual diameter of a bright shaft is $\frac{1}{16}$ in. less than the commercial diameter, it being designated from the diameter of the ordinary round bar iron from which it is turned. Thus, a length of what is called 3″ bright shafting is only $2\frac{15}{16}$ in. in diameter.

Cold-rolled shafting is designated by its commercial diameter; thus, a length of what is called 3″ shafting is 3 in. in diameter.

Cold-rolled iron is considerably stronger than ordinary turned wrought iron; the increased strength being due to the process of rolling, which seems to compress the metal and so make it denser—not merely skin deep, but practically throughout the whole diameter.

STRENGTH OF SHAFTING.

Let
D = diameter of shaft;
R = revolutions per minute;
H = horsepower transmitted;
C = constant given in table.

Constants for Line Shafting.

In the accompanying table the bearings are supposed to be spaced so as to relieve the shaft of excessive bending; also, in the third vertical column, an average number and weight of pulleys and power given off is assumed.

Material of Shaft.	No Pulleys Between Bearings.	Pulleys Between Bearings.
Steel or cold-rolled iron	65	85
Wrought iron	70	95
Cast iron	90	120

In determining the constants given in the accompanying table, allowance has been made to insure the stiffness as well as strength of the shaft.

$$H = \frac{D^3 \times R}{C}. \qquad D = \sqrt[3]{\frac{C \times H}{R}}. \qquad R = \frac{C \times H}{D^3}.$$

Shafts are subject to forces that produce stresses of two kinds—transverse and torsional. When the machines to be driven are below the shaft, there is a transverse stress on the shaft, due to the weight of the shaft itself, of the pulley and tension of the belt. Sometimes the power is taken off horizontally on one side, in which case the tension of the belt produces a horizontal transverse stress, while the weight of the pulley acts with the weight of the shaft to produce a vertical transverse stress. When the machinery to be driven is placed on the floor above the shaft, the tension of the belt produces a transverse stress in opposite direction to that due to the weight of the shaft and pulley.

The torsional strength of shafts, or their resistance to breaking by twisting, is proportional to the cube of their diameter. Their stiffness or resistance to bending is proportional to the fourth power of their diameters, and inversely proportional to the cube of the lengths of their spans. No simple general formula can be given that will safely apply to engine and other shafting that is subjected to the bending stresses produced by overhung cranks, the weight of heavy flywheels, the pull of large belts, or to severe shocks produced by the intermittent action of the power or load. The calculations for such shafts should always be based on the special conditions involved.

In the following table is given the maximum distance between the bearings of some continuous shafts that are used for the transmission of power.

Pulleys from which considerable power is to be taken should always be placed as close to a bearing as possible.

The diameters of the different lengths of shafts composing a line of shafting may be proportional to the quantity of power delivered by each respective length. In this connection, the positions of the various pulleys depend

on the distance between the pulley and the bearing, and on the amount of power given off by the pulleys. Suppose, for example, that a piece of shafting delivers a certain amount of power; then, it is obvious that the shaft will deflect or bend less if the pulley transmitting that power be placed close to a hanger or bearing, than if it be placed midway between the two hangers or bearings. It is impossible to give any rule for the proper distance of bearings that could be used universally, as in some cases the requirements demand that the bearings be nearer together than in others. If the work done by a line of shafting is distributed quite equally along its entire length, and the power can be applied near the middle, the strength of the shaft need be only half as great as would be required if the power were applied at one end of the shaft.

Diameter of Shaft. Inches.	Distance Between Bearings. Feet.	
	Wrought-Iron Shaft.	Steel Shaft.
2	11	11.50
3	13	13.75
4	15	15.75
5	17	18.25
6	19	20.00
7	21	22.25
8	23	24.00
9	25	26.00

WEIGHT OF CASTINGS.

To Find the Approximate Weight of a Casting.—For iron, multiply the weight of the pattern by 20. Copper is $\frac{1}{5}$ heavier; lead, $\frac{3}{5}$ heavier; brass, $\frac{1}{7}$ heavier; and zinc is $\frac{97}{100}$ as heavy.

Thickness or Diameter. Inches.	Weight of a Square Foot. Pounds.	Weight of a Square Bar 1 Ft. Long. Pounds.	Weight of a Round Bar 1 Ft. Long. Pounds.	Thickness or Diameter. Inches.	Weight of a Square Foot. Pounds.	Weight of a Square Bar 1 Ft. Long. Pounds.	Weight of a Round Bar 1 Ft. Long. Pounds.
$\frac{1}{4}$	9.375	.195	.154	$4\frac{1}{2}$	168.7	63.33	49.71
$\frac{3}{8}$	14.06	.440	.346	$4\frac{5}{8}$	173.4	66.86	52.52
$\frac{1}{2}$	18.75	.781	.610	$4\frac{3}{4}$	178.1	70.52	55.39
$\frac{5}{8}$	23.44	1.221	.959	$4\frac{7}{8}$	182.8	74.27	58.34
$\frac{3}{4}$	28.12	1.758	1.381	5	187.5	78.12	61.37
$\frac{7}{8}$	32.81	2.393	1.880	$5\frac{1}{4}$	196.9	86.14	67.65
1	37.50	3.125	2.455	$5\frac{1}{2}$	206.2	94.54	74.26
$1\frac{1}{8}$	42.19	3.955	3.107	$5\frac{3}{4}$	215.6	103.3	81.16
$1\frac{1}{4}$	46.87	4.883	3.835	6	225.0	112.5	88.36
$1\frac{3}{8}$	51.57	5.909	4.640	$6\frac{1}{4}$	234.4	122.1	95.89
$1\frac{1}{2}$	56.26	7.033	5.523	$6\frac{1}{2}$	243.8	132.0	103.7
$1\frac{5}{8}$	60.94	8.253	6.484	$6\frac{3}{4}$	253.1	142.4	111.9
$1\frac{3}{4}$	65.63	9.572	7.518	7	262.5	153.2	120.2
$1\frac{7}{8}$	70.32	10.99	8.630	$7\frac{1}{4}$	271.9	164.2	129.0
2	75.01	12.50	9.821	$7\frac{1}{2}$	281.3	175.8	138.1
$2\frac{1}{8}$	79.70	14.11	11.09	$7\frac{3}{4}$	290.7	187.7	147.4
$2\frac{1}{4}$	84.40	15.83	12.43	8	300.0	200.1	157.0
$2\frac{3}{8}$	89.07	17.63	13.85	$8\frac{1}{4}$	309.4	212.7	167.0
$2\frac{1}{2}$	93.75	19.54	15.34	$8\frac{1}{2}$	318.8	225.8	177.3
$2\frac{5}{8}$	98.44	21.54	16.56	$8\frac{3}{4}$	328.2	239.3	187.9
$2\frac{3}{4}$	103.2	23.64	18.56	9	337.4	253.1	198.8
$2\frac{7}{8}$	107.8	25.84	20.29	$9\frac{1}{4}$	346.8	267.4	210.0
3	112.6	28.13	22.10	$9\frac{1}{2}$	356.2	282.1	221.5
$3\frac{1}{8}$	117.3	30.52	23.97	$9\frac{3}{4}$	365.6	297.0	233.3
$3\frac{1}{4}$	121.8	33.01	25.93	10	375.0	312.5	245.5
$3\frac{3}{8}$	126.5	35.60	27.95	$10\frac{1}{4}$	384.4	328.4	257.8
$3\frac{1}{2}$	131.2	38.28	30.07	$10\frac{1}{2}$	393.7	344.5	270.6
$3\frac{5}{8}$	135.9	41.07	32.25	$10\frac{3}{4}$	403.1	361.2	283.7
$3\frac{3}{4}$	140.6	43.95	34.51	11	412.5	378.2	297.0
$3\frac{7}{8}$	145.3	46.93	36.85	$11\frac{1}{4}$	421.9	395.5	310.6
4	150.0	50.01	39.27	$11\frac{1}{2}$	431.2	413.3	324.6
$4\frac{1}{8}$	154.7	53.18	41.77	$11\frac{3}{4}$	440.6	431.4	338.8
$4\frac{1}{4}$	159.3	56.46	44.33	12	450.0	450.0	353.4
$4\frac{3}{8}$	164.0	59.82	46.99				

WEIGHTS OF SHEETS AND PLATES OF STEEL, WROUGHT IRON, COPPER, AND BRASS.

(*Cambria Steel Co.*)

AMERICAN, OR BROWN & SHARPE, GAUGE.

No. of Gauge.	Thickness. Inch.	Weight Per Square Foot.			
		Steel.	Iron.	Copper.	Brass.
0000	.460000	18.7680	18.4000	20.8380	19.6880
000	.409642	16.7134	16.3857	18.5568	17.5327
00	.364796	14.8837	14.5918	16.5253	15.6133
0	.324861	13.2543	12.9944	14.7162	13.9041
1	.289297	11.8033	11.5719	13.1052	12.3819
2	.257627	10.5112	10.3051	11.6705	11.0264
3	.229423	9.3605	9.1769	10.3929	9.8193
4	.204307	8.3357	8.1723	9.2551	8.7443
5	.181940	7.4232	7.2776	8.2419	7.7870
6	.162023	6.6105	6.4809	7.3396	6.9346
7	.144285	5.8868	5.7714	6.5361	6.1754
8	.128490	5.2424	5.1396	5.8206	5.4994
9	.114423	4.6685	4.5769	5.1834	4.8973
10	.101897	4.1574	4.0759	4.6159	4.3612
11	.090742	3.7023	3.6297	4.1106	3.8838
12	.080808	3.2970	3.2323	3.6606	3.4586
13	.071962	2.9360	2.8785	3.2599	3.0800
14	.064084	2.6146	2.5634	2.9030	2.7428
15	.057068	2.3284	2.2827	2.5852	2.4425
16	.050821	2.0735	2.0328	2.3022	2.1751
17	.045257	1.8465	1.8103	2.0501	1.9370
18	.040303	1.6444	1.6121	1.8257	1.7250
19	.035890	1.4643	1.4356	1.6258	1.5361
20	.031961	1.3040	1.2784	1.4478	1.3679
21	.028462	1.1612	1.1385	1.2893	1.2182
22	.025346	1.0341	1.0138	1.1482	1.0848
23	.022572	92094	90288	1.0225	.96608
24	.020101	.82012	80404	.91058	.86032
25	.017900	.73032	.71600	.81087	.76612
26	.015941	.65039	.63764	.72213	.68227
27	.014195	.57916	.56780	.64303	.60755
28	.012641	.51575	.50564	.57264	.54103
29	.011257	.45929	.45028	.50994	.48180
30	.010025	.40902	.40100	.45413	.42907
31	.008928	.36426	.35712	.40444	.38212
32	.007950	.32436	.31800	.36014	.34026
33	.007080	.28886	.28320	.32072	.30302
34	.006305	.25724	.25220	.28562	.26985
35	.005615	.22909	.22460	.25436	.24032
36	.005000	.20400	.20000	.22650	.21400
37	.004453	.18168	.17812	.20172	.19059
38	.003965	.16177	.15860	.17961	.16970
39	.003531	.14406	.14124	.15995	.15113
40	.003144	.12828	.12576	.14242	.13456

WEIGHT OF CAST-IRON PIPE PER FOOT IN POUNDS.

These weights are for plain pipe. For hautboy pipe, add 8 in. in length for each joint. For copper, add $\frac{1}{8}$; for lead, $\frac{3}{8}$; for welded iron, $\frac{1}{15}$.

Diameter of Bore. Inches.	Thickness of Pipe. Inches.												
	1/4	3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 3/4	2
1	3.07	5.07	7.38										
1 1/4	3.69	6.00	8.61										
1 1/2	4.30	6.92	9.84										
1 3/4	4.92	7.84	11.10										
2	5.53	8.76	12.30	16.2									
2 1/4	6.15	9.69	13.50	17.7									
2 1/2	6.76	10.60	14.80	19.2	24.0								
2 3/4	7.37	11.50	16.00	20.8	25.9								
3	7.98	12.50	17.20	22.3	27.7	33.4							
3 1/2	9.21	14.30	19.70	25.4	31.4	37.7							
4	10.30	16.10	22.20	28.5	35.1	42.0							
4 1/2	11.70	18.00	24.60	31.5	38.8	46.3							
5	12.90	19.80	27.10	34.6	42.5	50.6							
5 1/2	14.20	21.70	29.50	37.7	46.1	54.9							
6	15.40	23.50	32.00	40.8	49.8	59.2	68.9						
6 1/2	16.60	25.40	34.50	43.8	53.5	63.5	73.8	84.4					
7	17.80	27.20	36.90	46.9	57.2	67.8	78.7	89.4					
7 1/2	19.10	29.10	39.40	50.0	60.9	72.1	83.7	95.5	108				
8	20.30	30.90	41.80	53.1	64.6	76.4	88.6	101.0	114	127			
8 1/2	21.50	32.80	44.30	56.1	68.3	80.7	93.5	107.0	120	134	148		
9	22.80	34.60	46.80	59.2	72.0	85.1	98.4	112.0	126	140	155		
9 1/2	24.00	36.40	49.20	62.3	75.7	89.3	103.0	118.0	132	147	163		
10	25.10	38.30	51.70	65.3	79.4	93.6	108.0	123.0	138	164	170	202	
11	27.60	42.00	56.60	71.5	86.7	102.0	118.0	134.0	151	168	185	220	
12	30.00	45.70	61.50	77.7	94.1	111.0	128.0	145.0	163	181	199	237	275
13	32.50	49.40	66.40	83.8	102.0	120.0	138.0	156.0	175	195	214	254	294
14	35.00	53.10	71.40	89.4	109.0	128.0	148.0	168.0	188	208	229	271	314
15	37.40	56.70	76.30	96.1	116.0	137.0	158.0	179.0	200	222	244	289	334
16	39.10	60.40	81.20	102.0	124.0	145.0	167.0	190.0	212	235	258	306	353
17	42.30	64.10	86.10	108.0	131.0	154.0	177.0	201.0	225	249	273	323	373
18	44.80	67.80	91.00	115.0	139.0	163.0	187.0	212.0	237	262	288	340	393
19	47.30	71.50	96.00	121.0	146.0	171.0	197.0	223.0	249	276	303	357	412
20	49.70	75.20	101.00	127.0	153.0	180.0	207.0	234.0	261	289	317	375	432
21	52.20	78.90	106.00	133.0	161.0	188.0	217.0	245.0	274	303	332	392	452
22	54.60	82.60	111.00	139.0	168.0	196.0	227.0	256.0	286	316	347	409	471
23	57.10	86.30	116.00	145.0	175.0	206.0	236.0	267.0	298	330	362	426	491
24	59.60	89.90	121.00	152.0	183.0	214.0	246.0	278.0	311	343	375	444	511
25	62.00	93.60	126.00	158.0	190.0	223.0	256.0	289.0	323	357	391	461	531
26	64.50	97.30	131.00	164.0	198.0	231.0	266.0	300.0	335	370	406	478	550
27	66.90	101.00	135.00	170.0	205.0	240.0	276.0	311.0	348	384	421	495	570
28	69.40	105.00	140.00	176.0	212.0	249.0	286.0	323.0	360	397	436	512	590
29	71.80	109.00	145.00	182.0	220.0	257.0	295.0	334.0	372	411	450	530	609
30	74.20	112.00	150.00	188.0	227.0	266.0	305.0	345.0	384	424	465	547	629

DIAMETER AND NUMBER OF WOOD SCREWS.

Formulas for Wood Screws.

N = number

D = diameter

$$D = (N \times .01325) + .056$$

$$N = \frac{D - .056}{.01325}$$

No.	Diameter.	No.	Diameter.	No.	Diameter.
0	.056	11	.201	22	.347
1	.069	12	.215	23	.361
2	.082	13	.228	24	.374
3	.096	14	.241	25	.387
4	.109	15	.255	26	401
5	.122	16	.268	27	.414
6	.135	17	.281	28	.427
7	.149	18	.293	29	.440
8	.162	19	.308	30	.453
9	.175	20	.321		
10	.188	21	.334		

WEIGHT OF WROUGHT IRON.

The following table is for wrought iron. Multiply by .95 for weight of cast iron; by 1.02 for steel; by 1.16 for copper; by 1.09 for brass; by 1.48 for lead.

Thickness or Diameter. Inches.	Weight of a Square Foot. Pounds.	Weight of a Square Bar 1 Ft. Long. Pounds.	Weight of a Round Bar 1 Ft. Long. Pounds.	Thickness or Diameter. Inches.	Weight of a Square Foot. Pounds.	Weight of a Square Bar 1 Ft. Long. Pounds.	Weight of a Round Bar 1 Ft. Long. Pounds.
$\frac{1}{8}$	5.052	.0526	.0414	$4\frac{3}{8}$	176.8	64.47	50.63
$\frac{1}{4}$	10.10	.2105	.1653	$4\frac{1}{2}$	181.9	68.20	53.57
$\frac{3}{8}$	15.16	.4736	.3720	$4\frac{5}{8}$	186.9	72.05	56.59
$\frac{1}{2}$	20.21	.8420	.6613	$4\frac{3}{4}$	192.0	75.99	59.69
$\frac{5}{8}$	25.26	1.316	1.033	$4\frac{7}{8}$	197.0	80.05	62.87
$\frac{3}{4}$	30.31	1.895	1.488	5	202.1	84.20	66.13
$\frac{7}{8}$	35.37	2.579	2.025	$5\frac{1}{4}$	212.2	92.83	72.91
1	40.42	3.368	2.645	$5\frac{1}{2}$	222.3	101.9	80.02
$1\frac{1}{8}$	45.47	4.263	3.348	$5\frac{3}{4}$	232.4	111.4	87.46
$1\frac{1}{4}$	50.52	5.263	4.133	6	242.5	121.3	95.23
$1\frac{3}{8}$	55.57	6.368	5.001	$6\frac{1}{4}$	252.6	131.6	103.3
$1\frac{1}{2}$	60.63	7.578	5.952	$6\frac{1}{2}$	262.7	142.3	111.8
$1\frac{5}{8}$	65.68	8.893	6.985	$6\frac{3}{4}$	272.8	153.5	120.5
$1\frac{3}{4}$	70.73	10.31	8.101	7	282.9	165.0	129.6
$1\frac{7}{8}$	75.78	11.84	9.300	$7\frac{1}{4}$	293.0	177.0	139.0
2	80.83	13.47	10.58	$7\frac{1}{2}$	303.1	189.5	148.8
$2\frac{1}{8}$	85.89	15.21	11.95	$7\frac{3}{4}$	313.2	202.3	158.9
$2\frac{1}{4}$	90.94	17.05	13.39	8	323.3	215.6	169.3
$2\frac{3}{8}$	95.99	19.00	14.92	$8\frac{1}{4}$	333.4	229.3	180.1
$2\frac{1}{2}$	101.0	21.05	16.53	$8\frac{1}{2}$	343.5	243.4	191.1
$2\frac{5}{8}$	106.1	23.21	18.23	$8\frac{3}{4}$	353.6	247.9	202.5
$2\frac{3}{4}$	111.2	25.47	20.01	9	363.8	272.8	214.3
$2\frac{7}{8}$	116.2	27.84	21.87	$9\frac{1}{4}$	373.9	288.2	226.3
3	121.3	30.31	23.81	$9\frac{1}{2}$	384.0	304.0	238.7
$3\frac{1}{8}$	126.3	32.89	25.83	$9\frac{3}{4}$	394.1	320.2	251.5
$3\frac{1}{4}$	131.4	35.57	27.94	10	404.2	336.8	264.5
$3\frac{3}{8}$	136.4	38.37	30.13	$10\frac{1}{4}$	414.3	353.9	277.9
$3\frac{1}{2}$	141.5	41.26	32.41	$10\frac{1}{2}$	424.4	371.3	291.6
$3\frac{5}{8}$	146.5	44.26	34.76	$10\frac{3}{4}$	434.5	389.2	305.7
$3\frac{3}{4}$	151.6	47.37	37.20	11	444.6	407.5	320.1
$3\frac{7}{8}$	156.6	50.57	39.72	$11\frac{1}{4}$	454.7	426.3	334.8
4	161.7	53.89	42.33	$11\frac{1}{2}$	464.8	445.4	349.8
$4\frac{1}{8}$	166.7	57.31	45.01	$11\frac{3}{4}$	474.9	465.0	365.2
$4\frac{1}{4}$	171.8	60.84	47.78	12	485.0	485.0	380.9

SPIKES AND NAILS.

Standard Steel-Wire Nails.						Steel-Wire Spikes.			Common Iron Nails.		
Sizes.	Length. In.	Common.		Finishing.							
		Diam. In.	No. per Lb.	Diam. In.	No. per Lb.	Length. In.	Diam. In.	No. per Lb.	Size.	Length. In.	No. per Lb.
2d	1	.0524	1,060	.0453	1,558	3	.1620	41	2d	1	800
3d	$1\frac{1}{4}$	.0588	640	.0508	913	$3\frac{1}{2}$	.1819	30	3d	$1\frac{1}{4}$	400
4d	$1\frac{1}{2}$	.0720	380	.0508	761	4	.2043	23	4d	$1\frac{1}{2}$	300
5d	$1\frac{3}{4}$	.0764	275	.0571	500	$4\frac{1}{2}$	.2294	17	5d	$1\frac{3}{4}$	200
6d	2	.0808	210	.0641	350	5	.2576	13	6d	2	150
7d	$2\frac{1}{4}$	.0858	160	.0641	315	$5\frac{1}{2}$	.2893	11	7d	$2\frac{1}{4}$	120
8d	$2\frac{1}{2}$	.0935	115	.0720	214	6	.2893	10	8d	$2\frac{1}{2}$	85
9d	$2\frac{3}{4}$	.0963	93	.0720	195	$6\frac{1}{2}$	.2249	$7\frac{1}{2}$	9d	$2\frac{3}{4}$	75
10d	3	.1082	77	.0808	137	7	.2249	7	10d	3	60
12d	$3\frac{1}{4}$	.1144	60	.0808	127	8	.3648	5	12d	$3\frac{1}{4}$	50
16d	$3\frac{1}{2}$	.1285	48	.0907	90	9	.3648	$4\frac{1}{2}$	16d	$3\frac{1}{2}$	40
20d	4	.1620	31	.1019	62				20d	4	20
30d	$4\frac{1}{2}$	.1819	22						30d	$4\frac{1}{2}$	16
40d	5	.2043	17						40d	5	14
50d	$5\frac{1}{2}$	.2294	13						50d	$5\frac{1}{2}$	11
60d	6	.2576	11						60d	6	8

Weight, in Pounds, of 1 Lineal Foot of Wrought Iron—Flat.

Multiply by .95 for weight of cast iron; by 1.02 for weight of steel; by 1.16 for copper; by 1.09 for brass; by 1.48 for lead.

Size. Inches.	Weight. Pounds.	Size. Inches.	Weight. Pounds.	Size. Inches.	Weight. Pounds.
$1 \times \frac{1}{4}$	0.85	$5\frac{1}{4} \times \frac{3}{8}$	6.65	$4 \times \frac{5}{8}$	8.45
$1\frac{1}{4} \times \frac{1}{4}$	1.06	$5\frac{1}{2} \times \frac{3}{8}$	6.97	$4\frac{1}{4} \times \frac{5}{8}$	8.98
$1\frac{1}{2} \times \frac{1}{4}$	1.27	$5\frac{3}{4} \times \frac{3}{8}$	7.29	$4\frac{1}{2} \times \frac{5}{8}$	9.51
$1\frac{3}{4} \times \frac{1}{4}$	1.48	$6 \times \frac{3}{8}$	7.60	$4\frac{3}{4} \times \frac{5}{8}$	10.03
$2 \times \frac{1}{4}$	1.69			$5 \times \frac{5}{8}$	10.56
$2\frac{1}{4} \times \frac{1}{4}$	1.90	$1 \times \frac{1}{2}$	1.69	$5\frac{1}{4} \times \frac{5}{8}$	11.09
$2\frac{1}{2} \times \frac{1}{4}$	2.11	$1\frac{1}{4} \times \frac{1}{2}$	2.11	$5\frac{1}{2} \times \frac{5}{8}$	11.62
$2\frac{3}{4} \times \frac{1}{4}$	2.32	$1\frac{1}{2} \times \frac{1}{2}$	2.53	$5\frac{3}{4} \times \frac{5}{8}$	12.15
$3 \times \frac{1}{4}$	2.53	$1\frac{3}{4} \times \frac{1}{2}$	2.96	$6 \times \frac{5}{8}$	12.67
$3\frac{1}{4} \times \frac{1}{4}$	2.75	$2 \times \frac{1}{2}$	3.38		
$3\frac{1}{2} \times \frac{1}{4}$	2.96	$2\frac{1}{4} \times \frac{1}{2}$	3.80	$1 \times \frac{3}{4}$	2.53
$3\frac{3}{4} \times \frac{1}{4}$	3.17	$2\frac{1}{2} \times \frac{1}{2}$	4.22	$1\frac{1}{4} \times \frac{3}{4}$	3.17
$4 \times \frac{1}{4}$	3.38	$2\frac{3}{4} \times \frac{1}{2}$	4.65	$1\frac{1}{2} \times \frac{3}{4}$	3.80
$4\frac{1}{4} \times \frac{1}{4}$	3.59	$3 \times \frac{1}{2}$	5.07	$1\frac{3}{4} \times \frac{3}{4}$	4.44
$4\frac{1}{2} \times \frac{1}{4}$	3.80	$3\frac{1}{4} \times \frac{1}{2}$	5.49	$2 \times \frac{3}{4}$	5.07
$4\frac{3}{4} \times \frac{1}{4}$	4.01	$3\frac{1}{2} \times \frac{1}{2}$	5.92	$2\frac{1}{4} \times \frac{3}{4}$	5.70
$5 \times \frac{1}{4}$	4.22	$3\frac{3}{4} \times \frac{1}{2}$	6.33	$2\frac{1}{2} \times \frac{3}{4}$	6.33
$5\frac{1}{4} \times \frac{1}{4}$	4.44	$4 \times \frac{1}{2}$	6.76	$2\frac{3}{4} \times \frac{3}{4}$	6.97
$5\frac{1}{2} \times \frac{1}{4}$	4.65	$4\frac{1}{4} \times \frac{1}{2}$	7.18	$3 \times \frac{3}{4}$	7.60
$5\frac{3}{4} \times \frac{1}{4}$	4.86	$4\frac{1}{2} \times \frac{1}{2}$	7.60	$3\frac{1}{4} \times \frac{3}{4}$	8.24
$6 \times \frac{1}{4}$	5.07	$4\frac{3}{4} \times \frac{1}{2}$	8.03	$3\frac{1}{2} \times \frac{3}{4}$	8.87
		$5 \times \frac{1}{2}$	8.45	$3\frac{3}{4} \times \frac{3}{4}$	9.51
$1 \times \frac{3}{8}$	1.27	$5\frac{1}{4} \times \frac{1}{2}$	8.87	$4 \times \frac{3}{4}$	10.14
$1\frac{1}{4} \times \frac{3}{8}$	1.58	$5\frac{1}{2} \times \frac{1}{2}$	9.30	$4\frac{1}{4} \times \frac{3}{4}$	10.77
$1\frac{1}{2} \times \frac{3}{8}$	1.90	$5\frac{3}{4} \times \frac{1}{2}$	9.72	$4\frac{1}{2} \times \frac{3}{4}$	11.41
$1\frac{3}{4} \times \frac{3}{8}$	2.22	$6 \times \frac{1}{2}$	10.14	$4\frac{3}{4} \times \frac{3}{4}$	12.04
$2 \times \frac{3}{8}$	2.53			$5 \times \frac{3}{4}$	12.67
$2\frac{1}{4} \times \frac{3}{8}$	2.85	$1 \times \frac{5}{8}$	2.11	$5\frac{1}{4} \times \frac{3}{4}$	13.31
$2\frac{1}{2} \times \frac{3}{8}$	3.17	$1\frac{1}{4} \times \frac{5}{8}$	2.64	$5\frac{1}{2} \times \frac{3}{4}$	13.94
$2\frac{3}{4} \times \frac{3}{8}$	3.49	$1\frac{1}{2} \times \frac{5}{8}$	3.17	$5\frac{3}{4} \times \frac{3}{4}$	14.57
$3 \times \frac{3}{8}$	3.80	$1\frac{3}{4} \times \frac{5}{8}$	3.70	$6 \times \frac{3}{4}$	15.21
$3\frac{1}{4} \times \frac{3}{8}$	4.12	$2 \times \frac{5}{8}$	4.22		
$3\frac{1}{2} \times \frac{3}{8}$	4.44	$2\frac{1}{4} \times \frac{5}{8}$	4.75	$1\frac{1}{2} \times 1$	5.07
$3\frac{3}{4} \times \frac{3}{8}$	4.75	$2\frac{1}{2} \times \frac{5}{8}$	5.28	2×1	6.76
$4 \times \frac{3}{8}$	5.07	$2\frac{3}{4} \times \frac{5}{8}$	5.81	3×1	10.14
$4\frac{1}{4} \times \frac{3}{8}$	5.39	$3 \times \frac{5}{8}$	6.33	4×1	13.52
$4\frac{1}{2} \times \frac{3}{8}$	5.70	$3\frac{1}{4} \times \frac{5}{8}$	6.87	5×1	16.90
$4\frac{3}{4} \times \frac{3}{8}$	6.02	$3\frac{1}{2} \times \frac{5}{8}$	7.39	6×1	20.28
$5 \times \frac{3}{8}$	6.33	$3\frac{3}{4} \times \frac{5}{8}$	7.92	7×1	23.66

Strength of Metals in Pounds per Square Inch.

Material.	Ultimate Tensile.	Ultimate Compression.	Ultimate Shearing.	Modulus of Rupture.	Modulus of Elasticity. Millions.
Wrought iron	50,000	44,000	44,000	48,000	27
Shape iron	48,000				26
Structural steel	60,000 65,000	52,000	52,000	60,000	29
Cast iron	18,000	81,000	25,000	45,000	12
Steel, castings..............	70,000	70,000	60,000	70,000	30
Brass, cast	24,000	*30,000	36,000	20,000	9
Bronze, phosphor	50,000				14
Bronze, aluminum	75,000	120,000			
Aluminum, commercial	15,000	12,000	12,000		11

* Unit stress producing 10% reduction in original length.

Weight of Wrought-Iron Boltheads, Nuts, and Washers.

Diameter of Bolt. Inches.	Hexagon Heads and Nuts. Per Pair.	Square Heads and Nuts. Per Pair.	Round Washers. Per Pair.
1/4	20 to a lb.	16 to a lb.	20 to a lb.
3/8	10 to a lb.	8 1/3 to a lb.	10 to a lb.
1/2	5 to a lb.	4 1/6 to a lb.	5 to a lb.
5/8	2 3/4 to a lb.	2 1/2 to a lb.	3 to a lb.
3/4	2 to a lb.	0.56 lb.	0.63 lb.
7/8	0.77 lb.	0.88 lb.	0.77 lb.
1	1.25 lb.	1.31 lb.	1.25 lb.
1 1/8	1.75 lb.	2.10 lb.	1.75 lb.
1 1/4	2.13 lb.	2.56 lb.	2.25 lb.
1 3/8	3.00 lb.	3.60 lb.	3.25 lb.
1 1/2	3.75 lb.	4.42 lb.	4.25 lb.
1 5/8	4.75 lb.	5.70 lb.	5.25 lb.
1 3/4	5.75 lb.	7.00 lb.	6.50 lb.
1 7/8	7.27 lb.	8.72 lb.	8.00 lb.
2	8.75 lb.	10.50 lb.	9.60 lb.

Weight of 100 Bolts with Square Heads and Nuts.

(*The Carnegie Steel Co., Limited.*)

Length Under Head to Point.	Diameter of Bolts.								
	1/4″ Lb.	5/16″ Lb.	3/8″ Lb.	7/16″ Lb.	1/2″ Lb.	5/8″ Lb.	3/4″ Lb.	7/8″ Lb.	1″ Lb.
1 1/2	4.0	7.0	10.5	15.2	22.5	39.5	63.0		
1 3/4	4.4	7.5	11.3	16.3	23.8	41.6	66.0		
2	4.8	8.0	12.0	17.4	25.2	43.8	69.0	109.0	163
2 1/4	5.2	8.5	12.8	18.5	26.5	45.8	72.0	113.3	169
2 1/2	5.5	9.0	13.5	19.6	27.8	48.0	75.0	117.5	174
2 3/4	5.8	9.5	14.3	20.7	29.1	50.1	78.0	121.8	180
3	6.3	10.0	15.0	21.8	30.5	52.3	81.0	126.0	185
3 1/2	7.0	11.0	16.5	24.0	33.1	56.5	87.0	134.3	196
4	7.8	12.0	18.0	26.2	35.8	60.8	93.1	142.5	207
4 1/2	8.5	13.0	19.5	28.4	38.4	65.0	99.1	151.0	218
5	9.3	14.0	21.0	30.6	41.1	69.3	105.2	159.6	229
5 1/2	10.0	15.0	22.5	32.8	43.7	73.5	111.3	168.0	240
6	10.8	16.0	24.0	35.0	46.4	77.8	117.3	176.6	251
6 1/2			25.5	37.2	49.0	82.0	123.4	185.0	262
7			27.0	39.4	51.7	86.3	129.4	193.7	273
7 1/2			28.5	41.6	54.3	90.5	135.0	202.0	284
8			30.0	43.8	59.6	94.8	141.5	210.7	295
9				46.0	64.9	103.3	153.6	227.8	317
10				48.2	70.2	111.8	165.7	224.8	339
11				50.4	75.5	120.3	177.8	261.9	360
12				52.6	80.8	128.8	189.9	278.9	382
13					86.1	137.3	202.0	296.0	404
14					91.4	145.8	214.1	313.0	426
15					96.7	154.3	226.2	330.1	448
16					102.0	162.8	238.3	347.1	470
17					107.3	171.0	250.4	364.2	492
18					112.6	179.5	262.6	381.2	514
19					117.9	188.0	274.7	398.3	536
20					123.2	206.5	286.8	415.3	558
Per Inch Addit'al	1.4	2.1	3.1	4.2	5.5	8.5	12.3	16.7	21.8

IRON REQUIRED FOR ONE MILE OF TRACK.

TONS OF IRON.

Rule.—*To find the number of tons of rails to the mile, divide the weight per yard by 7, and multiply by 11. Thus, for 56-pound rail, divide 56 by 7 equal 8, multiplied by 11 equal 88 tons, for 1 mile of single track.*

Weight of Rail per Yard. Pounds.	Tons per Mile.		Weight of Rail per Yard. Pounds.	Tons per Mile.	
	Tons.	Pounds.		Tons.	Pounds.
12	18	1,920	45	70	1,600
14	22		48	75	960
16	25	320	50	78	1,280
18	28	640	52	81	1,600
20	31	960	56	88	
22	34	1,280	57	89	1,280
25	39	640	60	94	640
26	40	1,920	62	97	960
27	42	960	64	100	1,280
28	44		65	102	320
30	47	320	68	106	1,920
33	51	1,920	70	110	
35	55		72	113	320
40	62	1,920	76	119	960

NUMBER OF RAILS, SPLICES, AND BOLTS PER MILE OF TRACK.

Length of Rail. Feet.	No. of Rails per Mile.	No. of Splices.	No. of Bolts, 4 to Each Joint.	No. of Bolts, 6 to Each Joint.
18	586	1,168	2,336	3,504
20	528	1,056	2,112	3,168
21	503	1,006	2,012	3,018
22	480	960	1,920	2,880
24	440	880	1,760	2,640
25	422	844	1,688	2,532
26	406	812	1,624	2,436
27	391	782	1,564	2,346
28	377	754	1,508	2,262
30	352	704	1,408	2,112

RAILROAD SPIKES PER MILE OF TRACK.

Size Measured Under Head. Inches.	Average No. per Keg of 200 Lb.	Ties 2 Ft. Between Centers, 4 Spikes to a Tie.		Rails Used. Pounds per Yard.
		Pounds.	Kegs.	
$5\frac{1}{4} \times \frac{9}{16}$	375	5,870	$29\frac{1}{3}$	45 to 70
$5 \times \frac{9}{16}$	400	5,170	26	40 to 56
$5 \times \frac{1}{2}$	450	4,660	$23\frac{1}{3}$	35 to 40
$4\frac{1}{2} \times \frac{1}{2}$	530	3,960	20	28 to 35
$4 \times \frac{1}{2}$	600	3,520	$17\frac{2}{3}$	24 to 35
$4\frac{1}{2} \times \frac{7}{16}$	680	3,110	$15\frac{1}{2}$	20 to 30
$4 \times \frac{7}{16}$	720	2,910	$14\frac{3}{4}$	
$3\frac{1}{2} \times \frac{7}{16}$	900	2,350	11	16 to 25
$4 \times \frac{3}{8}$	1,000	2,090	$10\frac{1}{2}$	
$3\frac{1}{2} \times \frac{3}{8}$	1,190	1,780	9	16 to 20
$3 \times \frac{3}{8}$	1,240	1,710	$8\frac{1}{2}$	
$2\frac{1}{2} \times \frac{3}{8}$	1,342	1,575	$7\frac{7}{8}$	12 to 16

WIRE ROPES.

Wire ropes for mine use are made of either iron or steel, and are generally round. Flat wire ropes are sometimes used, but the round rope is the favorite for many reasons, and is generally used in American practice, excepting in some of the deep metal mines having small compartment shafts.

Taper ropes are sometimes used, the idea being to produce a rope of uniform strength, that is, to have it less strong and of less diameter at the cage end, where the load is least, and greater in strength and diameter at the drum end, where the load is greatest. The theory is correct, and some weight of rope is saved; but practically there is not much advantage, and it is doubtful whether taper ropes will ever be generally used. The long-established conviction that the best of all ropes for colliery use is a round one made of steel or iron has never been overcome and probably never will be.

Steel ropes are in most respects superior to iron ropes, and are therefore gaining in favor every year. The principal advantage of a steel rope is that it has a greater strength than an iron rope of equal diameter; consequently, it can be made lighter and can pass around pulleys and drums with less injury than an iron rope of equal strength.

In fastening a rope to a drum there is often a grievous error made. Men who will not think of passing a rope around a pulley of too small diameter will insert it in the drum rim in such a way as to make a very sharp curve, and make a weak point in the rope that would not otherwise exist. In the accompanying cut (*a*) shows the right and (*b*) the wrong way of passing the rope through the drum rim.


(a)


(b)

The securing of the rope to the drum or the drum shaft by several coils around each is unnecessary. With one coil around either the drum or the shaft, a pull of 1 lb. will resist a weight of 9 lb.; if two coils, a pull of 1 lb. will resist 9×9, or 81 lb.; if three coils, $9 \times 9 \times 9$, or 729 lb.; and so on, multiplying the former result by 9 for each additional coil.

No rope should be subjected to a load greater than the safe working strain. There is, of course, in all cases, a wide margin between the breaking strain and the working load, and on this account it is supposed that no risk is run by putting on a load considerably in excess of the maker's safe working strain. This is a mistake; and it is false economy. A rope overloaded is unduly strained, and, although showing no defect at the moment, it will some day give way without warning. Drums and rope pulleys should have as great diameters as the engines will allow. Ropes should be regularly and properly greased. This can best be done with brushes, but brush greasing takes considerable time. While it pays in the long run, it is not always convenient to use brushes. A fairly good and cheap arrangement for greasing ropes is to make a wooden trough, wide at top, and small enough at bottom to fit loosely around the rope. Make a mixture of 1 barrel of coal tar or pitch tar to 1 bushel of fresh slaked lime, and boil it well. Then fill the trough with this mixture and run the rope slowly through it.

A rope should not be changed from a large drum to a small one, for it will not work so well, neither will it last as long. This is also true, but in a lesser degree, of ropes changed from a small drum to a large one. After having been used for some time on a drum, the rope adapts itself to that diameter and resents a change. Rope sheaves should be made to fit the rope, and should be filled in with well-seasoned blocks of oak or other hard wood, set on end. This will save the rope and increase adhesion.

Where great flexibility is required, such as in hoisting ropes, the strands are usually made up of 19 wires each, while haulage ropes have but 7 wires to the strand; yet, both kinds have 6 strands. A hemp core is generally used, and in some cases a core is also placed in each strand, to further increase the flexibility of the rope.

The *lay* of the rope is the twist or pitch of the wires in the strand, or of the strands in the rope. As the lay of the wires is less than that of the strands, each wire is exposed to external wear for short distances at intervals

along the rope. In the ordinary lay, Fig. (*a*), the wires are twisted in the opposite direction to the strands. This method prevents the rope from untwisting when in use, and the wires from unraveling when they are worn through or broken at the surface. In the Lang lay, Fig. (*b*), the wires are twisted in the same direction as the strands, thus giving each wire a greater wearing surface, while the rope is smoother and will wear longer. After the wires begin to break, unraveling becomes troublesome, and it is more difficult to splice a Lang lay rope than an ordinary lay one. Hoisting ropes, especially those used to raise and lower men, should not be spliced. The locked wire rope, a cross-section of which is shown in Fig. (*c*), consists of wires of special cross-section formed in concentric layers. The lay of the inner wires is opposite to that of the outer ones, and somewhat longer. This prevents untwisting, and brings the greater stress upon the outside

(*a*)

(*b*)

(*c*)

layer, which is supposed to give way first. The inside layer, although inaccessible, and therefore cannot be inspected or oiled, can be relied upon until the external portion of the rope wears out. This form of rope has a smooth cylindrical surface, but it is not so flexible as the other forms, and is most suitable for haulage purposes or bucket transportation. The life of a steel rope depends largely on the conditions to which it is subjected, and the care it receives. At some mines the ropes must be changed every six months, while at others the ropes last for one year and longer. Where the rope enters the socket by which it is attached to the cage is perhaps the place where signs of weakness will first appear. This point should be frequently inspected, and a new connection made every two or three months by cutting a few feet off the end and paying it out from the drum end.

WEIGHTS AND STRENGTHS OF WIRE ROPES.

FLAT ROPES.

(*Trenton Iron Co., Trenton, N. J.*)

Size. Inches.	Approximate Weight per Foot. Pounds.	Breaking Stress. (Approximate.) Pounds.	
		Iron.	Cast Steel.
$2 \times \frac{3}{8}$	1.35	20,000	40,000
$2\frac{1}{2} \times \frac{3}{8}$	1.70	25,000	50,000
$3 \times \frac{3}{8}$	2.05	30,000	60,000
$3\frac{1}{2} \times \frac{3}{8}$	2.40	35,000	70,000
$4 \times \frac{3}{8}$	2.75	40,000	80,000
$5 \times \frac{3}{8}$	3.45	50,000	100,000
$6 \times \frac{3}{8}$	4.15	60,000	120,000
$3 \times \frac{1}{2}$	2.40	37,500	75,000
$3\frac{1}{2} \times \frac{1}{2}$	2.85	43,750	87,500
$4 \times \frac{1}{2}$	3.30	50,000	100,000
$5 \times \frac{1}{2}$	4.20	62,500	125,000
$6 \times \frac{1}{2}$	5.10	75,000	150,000
$7 \times \frac{1}{2}$	6.00	87,500	175,000
$8 \times \frac{1}{2}$	6.90	100,000	200,000

For safe working load allow from one-fifth to one-seventh of the breaking stress.

HOISTING, HAULAGE, AND TRANSMISSION ROPES.

Use of Rope.	Diameter. Inches.	Approximate Circumference. Inches.	Weight Per Lineal Foot. Pounds.	Swedish Iron. Approximate Breaking Strength. Tons.	Swedish Iron. Proper Working Load. Tons.	Swedish Iron. Proper Size of Drum or Sheave. Feet.	Crucible Cast Steel. Approximate Breaking Strength. Tons.	Crucible Cast Steel. Proper Working Load. Tons.	Crucible Cast Steel. Proper Size of Drum or Sheave. Feet.	Extra Strong Crucible Cast Steel. Approximate Breaking Strength. Tons.	Extra Strong Crucible Cast Steel. Proper Working Load. Tons.	Extra Strong Crucible Cast Steel. Proper Size of Drum or Sheave. Feet.	Plow Steel. Approximate Breaking Strength. Tons.	Plow Steel. Proper Working Load. Tons.	Plow Steel. Proper Size of Drum or Sheave. Feet.	Diameter. Inches.	Breaking Strength, Tons, New Manila Rope.
Hoisting Ropes. Six-Strand, 19-Wire. Hemp Center.	2¾	8⅝	11.95	114	22.8	15	228	45.6	11	266	53	11	305	61.0	15	2¾	26
	2½	7⅞	9.85	95	18.9	13½	190	37.9	10	222	45	10	254	50.8	13½	2½	21
	2¼	7⅛	8.00	78	15.6	12	156	31.2	9	182	36.4	9	208	41.6	12	2¼	17
	2	6¼	6.30	62	12.4	11	124	24.8	8	144	28.8	8	165	33.0	11	2	13½
	1¾	5½	4.85	48	9.6	9	96	19.2	7	112	22.4	7½	128	25.6	9	1¾	11
	1⅝	5	4.15	42	8.4	8½	84	16.8	6½	97	19.4	6½	111	22.2	8½	1⅝	9½
	1½	4¾	3.55	36	7.2	8	72	14.4	6	84	16.8	6	96	19.2	8	1½	8
	1⅜	4¼	3.00	31	6.2	7½	62	12.4	5½	72	14.4	5½	82	16.4	7½	1⅜	7
	1¼	4	2.45	25	5.0	7	50	10.0	5	58	11.6	5	67	13.4	7	1¼	6
	1⅛	3½	2.00	21	4.2	6	42	8.4	4½	49	9.8	4½	56	11.2	6	1⅛	5
	1	3	1.58	17	3.4	5	34	6.8	4	39	7.8	4	44	8.8	5	1	4
	⅞	2¾	1.20	13	2.6	4½	26	5.2	3½	30	6.0	3½	34	6.8	4½	⅞	3
	¾	2¼	.89	9.7	1.94	4	19.4	3.88	3	22	4.40	3	25	5.00	4	¾	2¼
	⅝	2	.62	6.8	1.36	3½	13.6	2.72	2½	15.8	3.16	2½	18	3.60	3½	⅝	1½
	9/16	1¾	.50	5.5	1.10	3	11.0	2.20	2¼	12.7	2.54	2¼	14.5	2.90	3	9/16	1¼
	½	1½	.39	4.4	.88	2¾	8.8	1.76	2	10.1	2.02	2	11.4	2.28	2¾	½	1
	7/16	1¼	.30	3.4	.68	2½	6.8	1.36	1¾	7.8	1.56	1¾	8.85	1.77	2½	7/16	¾
	⅜	1⅛	.22	2.5	.50	2	5.0	1.00	1½	5.78	1.15	1½	6.55	1.31	2	⅜	½
	5/16	1	.15	1.7	.34	1½	3.4	.68	1	4.05	.81	1	4.50	.90	1½	5/16	⅜
	¼	¾	.10	1.2	.24	¾	2.4	.48	½	2.70	.54	½	3.00	.60	¾	¼	3/16

Haulage and Transmission Ropes, Six-Strand, Seven-Wire, Hemp Center.

1½	4¾	3.55	34	6.80	11	68	13.6	8	79	15.8	8	91	18.2	11	1½
1⅜	4¼	3.00	29	5.80	10	58	11.6	7½	68	13.6	7½	78	15.6	10	1⅜
1¼	4	2.45	24	4.80	9¼	48	9.6	7	56	11.2	7	64	12.8	9¼	1¼
1⅛	3½	2.00	20	4.00	8	40	8.0	6	46	9.2	6	53	10.6	8	1⅛
1	3	1.58	16	3.20	6¾	32	6.4	5	37	7.4	5	42	8.4	6¾	1
7/8	2¾	1.20	12	2.40	6	24	4.80	4½	28	5.60	4½	32	6.4	6	7/8
3/4	2¼	.89	9.3	1.86	5¼	18.6	3.72	4	21	4.20	4	24	4.8	5¼	3/4
11/16	2⅛	.75	7.9	1.58	4¾	15.8	3.16	3¾	18.4	3.68	3¾	21	4.2	4¾	11/16
5/8	2	.62	6.6	1.32	4½	13.2	2.64	3½	15.1	3.02	3½	17	3.4	4½	5/8
9/16	1¾	.50	5.3	1.06	4	10.6	2.12	3	12.3	2.46	3	14	2.8	4	9/16
1/2	1½	.39	4.2	.84	3¾	8.4	1.68	2¾	9.70	1.94	2¾	11	2.20	3¾	1/2
7/16	1¼	.30	3.3	.66	3½	6.6	1.32	2½	7.50	1.50	2½	8.55	1.71	3½	7/16
3/8	1⅛	.22	2.4	.48	2¾	4.8	.96	2	5.58	1.11	2	6.35	1.27	2¾	3/8
5/16	1	.15	1.7	.34	2	3.4	.68	1½	3.88	.77	1½	4.35	.87	2	5/16
9/32	7/8	.125	1.4	.28	1¾	2.8	.56	1¼	3.22	.64	1¼	3.65	.73	1¾	9/32

The wire-rope table given on pages 120 and 121 is a rearrangement of the standard tables published in the catalogues of most of the American manufacturers of wire rope.

The proper working load given in this table is one-fifth of the approximate breaking stress, that is, a factor of safety of 5 is used, and when the values given in this table are used this factor is supposed to allow for the bending stress. The sizes of sheaves or drums given in this table are largely empirical, but they are based on a long experience in the use of wire ropes, and in most cases represent the minimum diameter recommended by the rope makers. The factor of safety of 5 assumes ordinary conditions of working; where the conditions are extraordinary, and particularly in cases where men are to be hoisted, a larger factor than 5 is used, varying from 5 to 10. Many elevator specifications require a factor of 10 to be used. When any factor but 5 is used, the proper working load is obtained by dividing the approximate breaking stress by the factor of safety assumed, or, if we know the load to be lifted and multiply this by the assumed factor, we obtain a certain value, and by comparing this with the values given in the table for the approximate breaking stress we can determine the size of rope, and the minimum diameter of sheave to use.

For example, suppose it is desired to determine the size of rope needed to hoist a load of 8 tons through a height of 300 feet. Multiplying 8 by 5, we have 40 tons, and from the table we find that the approximate breaking strength of a 1⅛-inch, crucible-steel hoisting rope is 42 tons. Such a rope weighs 2 pounds per foot; hence, the weight of the rope is $300 \times 2 = 600$ pounds, or .3 of a ton, and the total load on the rope is therefore 8.3 tons. $8.3 \times 5 = 41.5$, which is less than the approximate breaking stress for the given rope. The proper size of sheave or drum for this rope is given by the table as 4½ feet.

Galvanized wire is sometimes used in the manufacture of rope to prevent corrosion of the iron or steel of the wire. Galvanizing accomplishes this in the case of standing ropes but is not effective for running ropes, in which the friction of the rope against sheaves or drums soon wears off a portion of the zinc, and with both zinc and iron exposed and in contact with water, corrosion proceeds more rapidly than it would if the zinc were not present.

FLATTENED-STRAND ROPE.

These ropes have flattened strands, as shown in the accompanying cross-sections. Several wires thus take the wear of the rope instead of a single one, as is the case with a round strand when new. The manufacturers

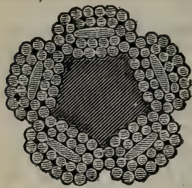


Fig. 1.

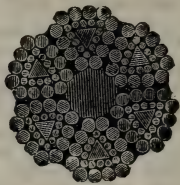


Fig. 2.

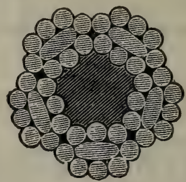


Fig. 3.

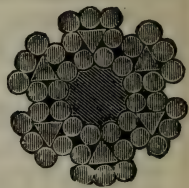


Fig. 4.

claim for these ropes longer life, more uniform wear, greater flexibility, less liability of wires becoming brittle, and freedom from all tendency to spin or kink. It is also claimed that the smoother surface effects considerable saving in the wear of pulleys and sheaves.

Patent Flattened-Strand Rope.

(*From A. Leschen & Sons Rope Co., St. Louis, Mo.*).

Use of Rope.	Diameter. Inches.	Approximate Circumference. Inches.	Weight per Lineal Foot. Pounds.	Swedish Iron.			Crucible Cast Steel.			Hercules.*	
				Approximate Breaking Strain. Tons of 2,000 lb.	Allowable Working Strain. Tons of 2,000 lb.	Minimum Size of Drum or Sheave. Feet.	Approximate Breaking Strain. Tons of 2,000 lb.	Allowable Working Strain. Tons of 2,000 lb.	Minimum Size of Drum or Sheave. Feet.	Approximate Breaking Strain. Tons of 2,000 lb.	Allowable Working Strain. Tons of 2,000 lb.
Hoisting Ropes.	2¼	7.06	8.50	75	15.0	10	176.0	35.2	9	260	52.0
	2	6.28	6.50	66	13.2	9	140.0	28.0	8	211	42.2
	1¾	5.49	5.00	54	10.8	7½	109 0	21.8	7¼	168	33.6
	1⅝	5.10	4.33	45	9.0	7	94.0	18.8	6¼		
	1½	4.71	3.71	40	8.0	6½	81.0	16.2	5¾	124	24.8
	1⅜	4.32	3.17	34	6.8	6	69.0	13.8	5½		
	1¼	3.92	2.50	28	5.6	5	56.0	11.2	5	84	16.8
	1⅛	3.53	2.15	21	4.2	4½	47.0	9.4	4½	67	13.4
	1	3.14	1.70	17	3.4	4	38.0	7.6	4	56	11.2
	⅞	2.74	1.25	13	2.6	3½	29.0	5.8	3½	40½	8.1
	¾	2.35	.96	9	1.8	3	21.0	4.2	3	32	6.4
	⅝	1.96	.67	6	1.2	2½	15.0	3.0	2	22½	4.5
	½	1.57	.44	4	.8	1¾	9.5	1.9	1½	13½	2.7
Haulage and Transmission Ropes.	1¼	3.92	2.40	27.0	5.4	10¾	54.	10.8	7¼	80	16.0
	1⅛	3.53	2.00	22.5	4.5	9½	45.	9.0	6¼	64	12.8
	1	3.14	1.64	18.0	3.6	8½	36.	7.2	5¾	53	10.6
	⅞	2.75	1.20	13.5	2.7	7½	27.	5.4	5	38	7.6
	¾	2.35	.93	10.0	2.0	6¾	20.	4.0	4½	30	6.0
	⅝	1.96	.68	7.0	1.4	5¼	14.	2.8	3½	21	4.2
	½	1.57	.40	4.5	.9	4	9.	1.8	2½	13	2.6
	⅜	1.17	.25				5.	1.0	2		

*Hercules wire rope is made from wire specially drawn from a patent tempered steel made solely for this brand of rope. The manufacturers claim for it a combination of strength, toughness, pliability, and perfect elastic properties. It can be used over the same drums and sheaves as ordinary wire rope, thus making unnecessary any change in plant.

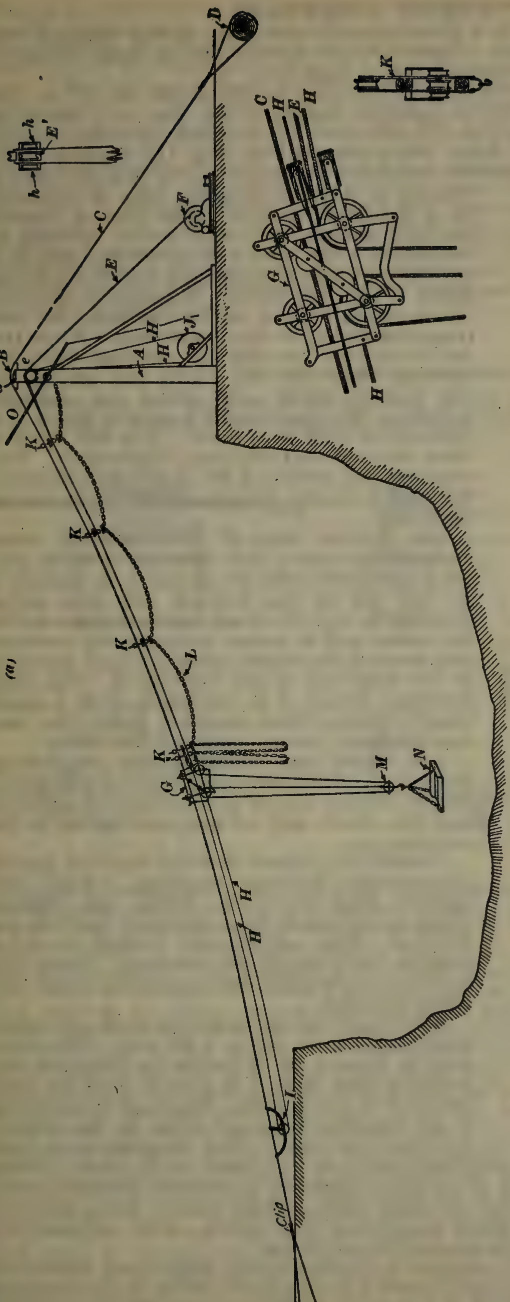


FIG. 1.

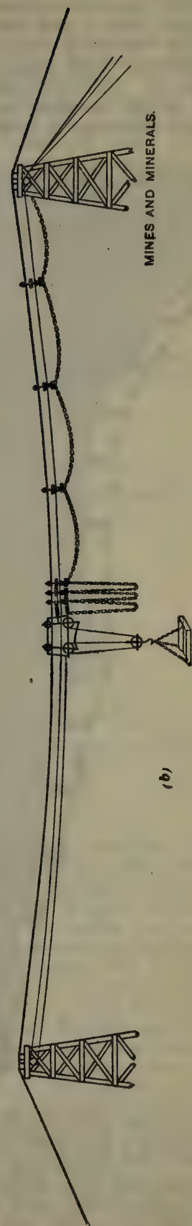


FIG. 2.

SUSPENSION CABLEWAYS.

A suspension cableway is a hoisting and conveying device using a suspended cable for a trackway. There are two types: the inclined, or semi-gravity, Fig. 1, and the horizontal, Fig. 2, page 122a.

The inclined cableway consists of a cable inclined 20° to 22° to the horizontal, and passing over a cast-iron saddle *B* on top of a tower or frame *A*. It is anchored by logs *D* buried about 5 feet underground, or from iron plugs secured in the rock, when the rock is near the surface. The trolley carriage *G* runs down the incline of the cableway by gravity until it reaches a stop. A hoisting rope *E* operated by a winding drum *F* leads over a sheave pulley *e*, thence to a pulley in the carriage *G*, thence to a fall block *M*, upwards again to a second pulley in the carriage, and downwards again to the fall block. Winding in the rope hoists the fall block to the carriage, the carriage remaining at the lower stop. When the fall block collides with the carriage, both the carriage and the fall block are pulled up the incline cable, and when the carriage arrives at the head-tower, a gate, or hook, *O* is lowered to hold it in place. The fall block is then lowered and the load discharged. The engine *F* has usually a 10″ × 12″ double cylinder and a single friction drum 37 inches in diameter.

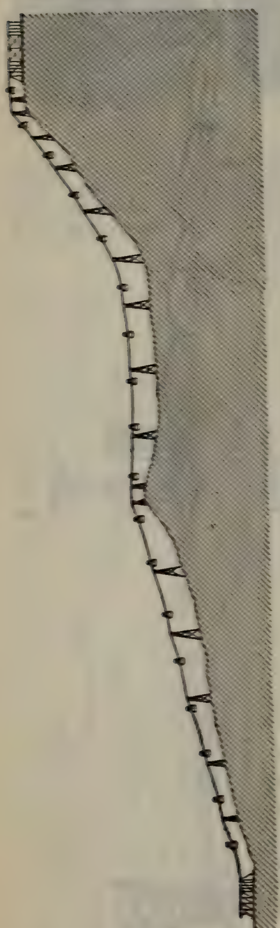


Fig. 3.

An endless rope *H* takes several turns around the sheave *J* to prevent it from slipping, and both ends are passed over sheaves *h* at the top of the derrick, one end being secured to the front of the carriage, while the other end is taken through the carriage and around the return sheave *I* and fastened to the rear end of the carriage *G*. The endless-rope wheel *J* is provided with a band brake, which, when applied, holds the carriage securely at any point on the cable.

All ropes pass through the supporting trolleys *K*, which are connected by a chain *L*. These trolleys follow the carriage by gravity, and the chain may or may not be fast to the carriage.

Instead of chain-connected trolleys, patent button-stop, fall-rope carriers, which are lighter, may be used. These are spaced along an auxiliary rope on which buttons are screwed. The carriers are picked up by a horn on the front of the carriage. These are said to be cheaper for operation than the chain trolleys.

The length of the span for inclined cableways varies from 200 to 1,200 feet. The main rope is from $1\frac{1}{2}$ to $2\frac{1}{4}$ inches in diameter, the hoisting rope from $\frac{5}{8}$ to $\frac{3}{4}$ inch, and the endless rope $\frac{7}{16}$ and $\frac{1}{2}$ inch. The rope mostly used is six strands, nineteen wires to the strand, crucible cast steel. The hoisting rope lasts from 1 year to 2 years, and the main cable from 5 years to 10 years. These cableways are widely used about slate quarries in Eastern Pennsylvania, where the operating expense for each cable, where two or more are connected with one boiler, is about \$5 per day of 10 hours. This includes the engineer, steam, and maintenance of the cableway.

The horizontal cableway requires a double friction drum and reversible link-motion engine. It may be operated at any inclination of the carrying cable and either from the high or low point of the support, though, if possible, it should be from the higher end. The endless, or traction, rope is attached to one of the drums of the engine and the engineer thus has complete control of the carriage; hence, because of its greater applicability, this

system is supplanting the inclined, although the inclined costs one-fourth less for installation. The method of operation is similar to the inclined. The amount of rope required is the same in each system. A horizontal cableway of the Hamilton Coal Co., near Tarentum, Pa., has a span of 2,200 feet. The stationary rope is 2,500 feet long and $2\frac{1}{4}$ inches in diameter. The hoisting rope is 4,500 feet long and $\frac{5}{8}$ inch in diameter. The head-tower is 80 feet high, the tail-tower is 100 feet, and the rope deflects 80 feet. The skip used holds 3 tons of coal and makes 10 trips per hour. Five men operate the plant and it takes 2 tons of coal for the engine. Based on a capacity of 100 tons per day, the cost of carrying the coal is 13 cents per ton. For a cableway of average length, 1,000–1,500 feet, the cost of operation should not be one-half the above cost. A cableway 2,140 feet long was used in constructing the dam at the power plant at Glens Falls, N. Y.

One or both towers of a cableway may be mounted on wheels capable of moving on a track at right angles to the cable and the cableway then made to cover a wide territory.

WIRE-ROPE TRAMWAYS.

A tramway, in America, is a cableway of the horizontal type consisting of a number of spans. In England, the term cableway includes tramways.

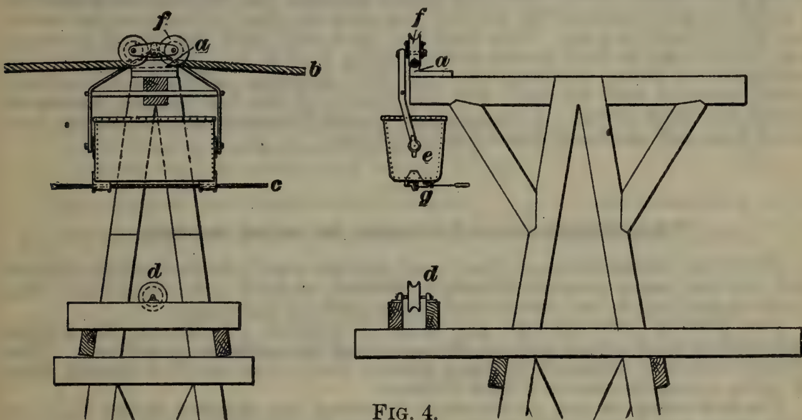


FIG. 4.

Single Tramways.—Single wire-rope tramways have a single moving rope, which serves to support and advance the load at one and the same time, Fig. 3. This rope passes over suitable sheaves at the intermediate supports, and the load is carried in buckets suspended from it by gooseneck or straight hangers. The hangers are usually attached to the cable by means of a clip, which is either inserted in the center of the cable or strapped to it. The carriers are often loaded and unloaded while in motion, the loading being accomplished by a traveling mechanical hopper and the unloading by a drop bottom to the bucket. If the line is level, or the grade light, the hangers are provided with box heads filled with wood or leather and rubber, which rest on the rope; the rubber or wood providing sufficient friction to prevent the hanger's slipping. With this system, long spans are evidently out of the question, because with a long span the angle of the rope in the vertical plane, at the supports, becomes so great that the friction will not hold the box head. For all practical purposes, grades exceeding 1:4 are to be avoided; and for steeper grades, to prevent slipping, a clamp or a clip inserted in the rope is used to fasten the hanger to the rope.

The single moving-rope tramways carry loads not exceeding 200 pounds. The speed of the rope for the variety in which the hangers are fastened to the rope may be as high as 450 feet per minute, and for one in which the hanger is loose, 200 feet per minute. The single moving-rope tramway has a capacity up to 200 tons per day, and may be built, say, $1\frac{1}{2}$ to 2 miles long.

Double Tramways.—The more satisfactory and substantial kind of wire-rope tramways has one or more fixed ropes which constitute the permanent

way, and an endless traction rope. The loaded carrier travels outwards on one fixed cable and returns by a parallel one suspended from the opposite side of the same supports. The terminals have suitable appliances for loading and unloading the buckets, either by hand or automatically.

The intermediate supports are built of wood or steel framing, with saddles of cast iron *a*, Fig. 4, in which the fixed cables *b* rest. The traction rope *c* is supported (in the absence of a bucket) by the rollers *d*, set conveniently on the supports. The load is carried in buckets *e*, or other contrivances suitable for the purpose, which are suspended from a trolley *f*, which runs on the fixed cables, the wheels of which are large enough to pass over the rope couplings, and also to clear the saddles. Grips *g* attach the carriers to the traction rope. These grips may be operated by hand or automatically.

This kind of tramway is capable of carrying individual loads up to 1,400 or 1,500 pounds, not including the weights of the bucket and hanger itself. The speed of traction rope may be from 150 to 350 feet per minute. The capacity is from 200 to 1,000 tons per day of 10 hours. These figures represent good, safe practice, but they are not, of course, inflexible.

The maximum length of line which may be built in one section varies largely with conditions of load, spacing of supports, contour of ground, etc. Wire-rope tramways work under great difficulties, and probably 2½ to 4 miles is the economical limit. This has been exceeded, but the trouble is that for a much greater distance the friction becomes too great for economical working of the traction rope. This does not, however, limit the length of tramway which may be built, as the power station may be located at a convenient intermediate point, dividing the line into sections. Several intermediate power stations may be used, and the length of the line greatly increased above the limit given. A tramway at Grand Encampment, Wyoming, is 16 miles long and carries 40 tons of ore per hour.

TRANSMISSION OF POWER BY WIRE ROPES.

The term transmission, as here used, applies simply to the modification of belt driving, using grooved wheels or sheaves at each end of the line. The power is applied to one sheave and taken off from the other.

The friction between rope and sheaves depends directly on the weight and tension of the rope and on the nature of the surfaces in contact. This pressure is better obtained by using a large, heavy rope at a low tension than by using a smaller rope at a high tension.

The deflection or sag of the rope, between the sheaves, is the same for both upper and lower parts of the rope when the transmission is not running and should be, according to John A. Roebling's Sons Co., equal to about one-thirty-sixth of the span. The deflection may be calculated by the formula from the Trenton Iron Co.:

$$h = \frac{w\,s^2}{8t};$$

in which h = the deflection in feet;
w = weight of the rope per foot, in pounds;
s = span, in feet;
t = tension, in pounds.

When driving from the under side, this part of the rope will be tightened and its deflection decreased, while the upper part of the rope becomes slackened and its deflection increased. Under proper conditions the deflection of the lower rope should be about one-fiftieth, and that of the upper about one-twenty-fifth of the span. The difference in the tensions of the two parts of the rope is the effective pull of the driving sheaves, enabling power to be transmitted.

Transmission ropes are subject to three stresses, viz.:

(1) The direct tension, due to the power transmitted, plus the friction and weight of the rope; (2) the bending stress, due to the bending of the rope around the sheaves; (3) the centrifugal tension, due to the centrifugal force in the rapidly running rope.

The following data on stresses in transmission ropes are given by Mr. Wm. Hewitt, of the Trenton Iron Co.

In transmitting power by wire rope, working tension should not exceed

the difference between the maximum safe stress and the bending stress. It may be greater, therefore, as the bending stress is less, but to avoid slipping a certain ratio must exist between the tensions in taut and slack portions of the rope when running, which is determined by the formula

$$T = S e^{fn\pi};$$

in which T = tension in the taut portion of the rope;
S = tension in the slack portion;
e = base of the Naperian system of logarithms = 2.7182818;
n = number of half laps of rope about sheaves or drums at either end of line;
π = 3.1416;
f = coefficient of friction depending on the kind of filling in the grooves of the sheaves, or character of the material on which the rope tracks.

The useful effort of transmitting force is the difference between the tension of the taut and slack portions of the rope. $T - S = S(e^{fn\pi} - 1)$, and to obtain this, the initial tension, or tension when the rope is at rest, must be one-half the sum of the two tensions.

$$T + S = S(e^{fn\pi} + 1) = \frac{e^{fn\pi} + 1}{e^{fn\pi} - 1}(T - S).$$

The following are some of the values of f:

Dry rope on a grooved iron drum	.120
Wet rope on a grooved iron drum	.085
Greasy rope on a grooved iron drum	.070
Dry rope on wood-filled sheaves	.235
Wet rope on wood-filled sheaves	.170
Greasy rope on wood-filled sheaves	.140
Dry rope on rubber and leather filling	.495
Wet rope on rubber and leather filling	.400
Greasy rope on rubber and leather filling	.205

The values of the coefficients $e^{fn\pi}$ and $\frac{e^{fn\pi} + 1}{e^{fn\pi} - 1}$ corresponding to the above values of f, for one up to six half laps of the rope, are as follows:

VALUES OF $e^{fn\pi}$.

f =	n = Number of Half Laps About Sheaves or Drums at Either End of Line.					
	1	2	3	4	5	6
.070	1.246	1.552	1.934	2.410	3.003	3.741
.085	1.306	1.706	2.228	2.910	3.801	4.964
.100	1.369	1.875	2.566	3.514	4.810	6.586
.120	1.458	2.125	3.099	4.518	6.586	9.602
.130	1.504	2.263	3.405	5.122	7.706	11.593
.140	1.552	2.410	3.741	5.808	9.017	13.998
.150	1.602	2.566	4.111	6.586	10.551	16.902
.170	1.706	2.910	4.964	8.467	14.445	24.641
.200	1.875	3.514	6.586	12.346	23.140	43.376
.205	1.904	3.626	6.904	13.146	25.031	47.663
.235	2.092	4.378	9.160	19.166	40.100	83.902
.250	2.193	4.810	10.551	23.140	50.637	111.318
.265	2.299	5.286	12.153	27.941	64.239	147.693
.300	2.566	6.586	16.902	43.376	111.318	285.680
.350	3.001	9.017	27.077	81.307	244.152	733.145
.400	3.514	12.346	43.376	152.405	535.488	1,849.140
.410	3.626	13.146	47.663	172.814	626.577	2,271.775
.450	4.111	16.902	69.487	285.680	1,174.480	4,828.510
.495	4.716	22.425	106.194	502.881	2,381.400	
.500	4.810	23.140	111.318	535.488	2,575.940	

VALUES OF $\frac{e^{f n \pi}+1}{e^{f n \pi}-1}$.

f =	n = Number of Half Laps About Sheaves or Drums at Either End of Line.					
	1	2	3	4	5	6
.070	9.130	4.623	3.141	2.418	1.999	1.729
.085	7.536	3.833	2.629	2.047	1.714	1.505
.100	6.420	3.287	2.280	1.795	1.525	1.358
.120	5.345	2.777	1.953	1.570	1.358	1.232
.130	4.968	2.584	1.832	1.485	1.298	1.189
.140	4.623	2.418	1.729	1.416	1.249	1.154
.150	4.322	2.280	1.643	1.358	1.209	1.126
.170	3.833	2.047	1.505	1.268	1.149	1.085
.200	3.287	1.795	1.358	1.176	1.090	1.047
.205	3.212	1.762	1.338	1.165	1.083	1.043
.235	2.831	1.592	1.245	1.110	1.051	1.024
.250	2.676	1.525	1.209	1.090	1.040	1.018
.265	2.539	1.467	1.179	1.072	1.032	1.014
.300	2.280	1.358	1.126	1.047	1.018	1.007
.350	2.000	1.249	1.077	1.025	1.008	1.003
.400	1.795	1.176	1.047	1.013	1.004	1.001
.410	1.765	1.164	1.043	1.012	1.003	1.001
.450	1.643	1.126	1.029	1.007	1.002	1.000
.495	1.538	1.093	1.019	1.004	1.001	1.000
.500	1.525	1.090	1.018	1.004	1.001	1.000

For a given diameter of sheave, and a variable diameter of wire, a ratio exists between these diameters corresponding to a maximum working tension. This ratio results, approximately, in a working tension of one-third and bending stress of two-thirds of the maximum safe tension, which is from one-third to two-fifths of the ultimate stress, and practically determines the minimum diameter of sheave for any rope. The ratio for any size of wire varies slightly, according to the number of wires composing the rope, and in terms of rope diameter is,

	Steel	Iron
For 7-wire rope	79.6	160.5
For 12-wire rope	59.3	120.0
For 19-wire rope	47.2	95.8

from which we derive the following table:

DIAMETERS OF MINIMUM SHEAVES IN INCHES.

Diameter of Rope.	Steel.			Iron.		
	7-Wire.	12-Wire.	19-Wire.	7-Wire.	12-Wire.	19-Wire.
$\frac{1}{4}$	20	15	12	40	30	24
$\frac{5}{16}$	25	19	15	50	38	30
$\frac{3}{8}$	30	22	18	60	45	36
$\frac{7}{16}$	35	26	21	70	53	42
$\frac{1}{2}$	40	30	24	80	60	48
$\frac{9}{16}$	45	33	27	90	68	54
$\frac{5}{8}$	50	37	30	100	75	60
$\frac{11}{16}$	55	41	32	110	83	66
$\frac{3}{4}$	60	44	35	120	90	72
$\frac{7}{8}$	70	52	41	140	105	84
1	80	59	47	160	120	96

Sheaves.—To decrease the bending stresses the sheaves for wire-rope transmissions are generally of as large diameter as is practicable to give the required speed to the rope. Large sheaves are also advantageous because with them the rope is run at a high velocity allowing of a lower tension, and permitting a rope of smaller diameter to be used than would be possible with smaller sheaves, provided, of course, that the span is of sufficient length to give the necessary weight.

Sheaves are generally made of cast iron when not exceeding 12 feet in diameter, and when larger than this they are usually built up with wrought-iron arms. Sheaves, upon which the rope is to make but a single half-turn, are made with **V**-shaped grooves in their circumference. The bottom part of the groove is widened to receive the filling, which consists of some substance to give a bed for the rope to run on and protect it from wear, and to increase the friction so that the rope will not slip. This filling is made of blocks of wood, rubber, and leather, or other material. Rubber and leather have been used separately, but blocks of rubber separated by pieces of leather have been found to give the best results.

Power Transmitted.—The horsepower transmitted is equal to the resistance overcome (the effective pull), in pounds, multiplied by the speed of the rope, in feet per minute, and divided by 33,000, that is (formula from John A. Roebling's Sons Co.),

$$H = \frac{T\,V}{33{,}000};$$

in which $H =$ horsepower transmitted;
$T =$ difference in tension between the driving and driven sides of the rope;
$V =$ speed of the rope, in feet per minute.

In applying this formula, V is either given or assumed. T is equal to the weight of the rope suspended between the sheaves multiplied by three (for the proportion of deflection stated).

To transmit a given horsepower, the speed of the rope may be increased and the tension (effective pull) correspondingly decreased, and a smaller rope may be used provided other considerations will allow it.

For determining the horsepower that can be transmitted over a given transmission, the following formula is given by the Trenton Iron Co.:

$$H = [c\,d^2 - .000006\,(W + g' + g'')]\,s;$$

in which $H =$ horsepower that can be transmitted;
$c =$ constant depending on material of rope, the filling in the grooves of the sheaves, and the number of half laps about the sheaves or drums at either end of the line;
$d =$ diameter of rope, in inches;
$W =$ weight of rope, in pounds;
$g' =$ weight of terminal sheaves and shafts;
$g'' =$ weight of intermediate sheaves and shafts.

The following table gives the value of c for ropes on different materials:

VALUE OF C FOR ROPES ON DIFFERENT MATERIALS.

$c =$ for Steel Rope on	Number of Half Laps About Sheaves or Drums at Either End of Line.					
	1	2	3	4	5	6
Iron	5.61	8.81	10.62	11.65	12.16	12.56
Wood	6.70	9.93	11.51	12.26	12.66	12.83
Rubber and Leather	9.29	11.95	12.70	12.91	12.97	13.00

The values of c for iron rope are one-half of the above.

It is evident from the above figures that when more than three laps are made it is immaterial what the surface is on which the rope tracks, as far as frictional adhesion is concerned.

From the foregoing formula, assuming the sheaves to be of equal diameter, and of a size not less than the minimum diameter given in the table, we deduce the following:

HORSEPOWER CAPABLE OF BEING TRANSMITTED BY A STEEL ROPE MAKING A SINGLE LAP ON WOOD-FILLED SHEAVES

Diameter of Rope in Inches.	Velocity of Rope in Feet per Second.									
	10	20	30	40	50	60	70	80	90	100
$\frac{1}{4}$	4	8	13	17	21	25	28	32	37	40
$\frac{5}{16}$	7	13	20	26	33	40	44	51	57	62
$\frac{3}{8}$	10	19	28	38	47	56	64	73	80	89
$\frac{7}{16}$	13	26	38	51	63	75	88	99	109	121
$\frac{1}{2}$	17	34	51	67	83	99	115	130	144	159
$\frac{9}{16}$	22	43	65	86	106	128	147	167	184	203
$\frac{5}{8}$	27	53	79	104	130	155	179	203	225	247
$\frac{11}{16}$	32	63	95	126	157	186	217	245		
$\frac{3}{4}$	38	76	103	150	186	223				
$\frac{7}{8}$	52	104	156	206						
1	68	135	202							

The horsepower that may be transmitted by iron ropes is one-half of the above.

The foregoing table gives the maximum amount of power capable of being transmitted under the conditions stated, so that in using wood-lined sheaves, it is well to make some allowance for the stretching of the rope, and to advocate somewhat heavier equipments than the above table would give; that is, if it is desired to transmit 20 horsepower, for instance, to put in a plant that would transmit 25 to 30 horsepower, thus avoiding the necessity of having to take up a comparatively small amount of stretch. On rubber and leather filling, however, the amount of power capable of being transmitted is considerably greater than on wood, so that this filling is generally used; and in this case no allowance need be made for stretch, as such sheaves will likely transmit the power given by the table, under all possible deflections of the rope.

The transmission of more than 250 horsepower is impracticable with filled sheaves, since the tension is so great that the filling would quickly cut out, and the frictional adhesion on a metallic surface is insufficient where the rope makes but a single lap, or a half lap at either end of the line.

GLOSSARY OF ROPE TERMS.

Annealed Wire Rope.—A wire rope made from wires that have been softened by annealing and the tensile strength thereby lowered.

Bending Stress.—The stress produced in the outer fibers of a rope by bending over a sheave or drum.

Breaking Strain, Breaking Strength, Breaking Stress.—The least load that will break a rope. These terms are used indiscriminately to mean the load which will break a rope. The stress on a rope at the moment of breaking is the *breaking stress*, and the strain or deformation produced in the material by this stress is the *breaking strain*.

Bright Rope.—Rope of any construction, whose wires have not been galvanized, tinned, or otherwise coated.

Cable-Laid Rope.—A term applied to wire cables made of several ropes twisted together, each rope being composed of strands twisted together without limitation as to the number of strands or direction of twist. A fiber cable-laid rope is a rope having three strands of hawser-laid rope, twisted right-handed.

Cable.—Same as cable-laid rope; a fiber cable consists of three hawsers laid up left-handed.
Cast Steel.—Steel that has been melted, cast into ingots, and rolled out into bars.
Clamp.—A device for holding two pieces or parts of rope together by pressure.
Clip.—A device similar to a clamp but smaller and for the same purpose.
Coir.—Coconut-husk fiber.
Compound.—A lubricant applied to the inside and outside of ropes preventing corrosion and lessening abrasion of the rope when in contact with hard surfaces.
Core.—The central part of a rope forming a cushion for the strands. In wire ropes it is sometimes made of wire, but usually it is of hemp, jute, or some like material.
Coupling.—A device for joining two rope ends without splicing.
Crucible Steel.—A fine quality of steel made by the crucible process.
Drum.—The part of a hoisting engine on which the rope is wound.
Elastic Limit.—The elastic limit is that point at which the deformations in the material cease to be proportional to the stresses.
Elevator Rope.—A rope used to operate an elevator.
Endless Rope.—A rope which moves in one direction, one part of which carries loaded cars from a mine at the same time that another part brings the empties into the mine.
Fiber.—A single thread-like filament.
Flat Rope.—A rope in which the strands are woven or sewed together to form a flat, braid-like rope.
Flattened-Strand Rope.—A wire rope whose strands are flattened or oval and which therefore presents an increased wearing surface over that of the ordinary round-strand rope.
Flattened-Strand Triangular Rope.—A wire rope of the flattened-strand construction in which the strands are triangular in shape.
Fleet.—Movement of a rope sideways in winding on a drum.
Fleet Wheel.—A grooved wheel or sheave that serves as a drum and about which one or more coils of a haulage rope pass.
Galvanized Rope.—Rope made of wires that have been galvanized or coated with zinc to protect them from corrosion.
Grip Wheel.—A wheel, the periphery of which is fitted with a series of toggle-jointed, cast-steel jaws that grip the rope automatically.
Guy.—A strand or rope used to support a pole, structure, derrick, or chimney, etc.
Haulage Rope.—A rope used for haulage purposes.
Hawser.—A term applied to any wire rope used for towing on lake or sea. A fiber hawser consists of three strands laid up right-handed.
Hawser-Laid Rope has three strands of yarn twisted left-handed, the yarns being laid up right-handed. Synonymous with cable-laid rope as applied to wire ropes.
Hawser Wire Rope.—Galvanized ropes of iron or steel usually composed of six strands, 12 wires each, principally used in marine work for towing purposes.
Hemp.—A tough, strong fiber obtained from the hemp plant.
Hoisting Rope.—A rope composed of a sufficient number of wires and strands to insure flexibility. Such ropes are used in shafts, elevators, quarries, etc.
Idler.—A sheave or pulley running loose on a shaft to guide or support a rope.
Jute.—A fiber obtained from the inner bark of two Asiatic herbs: *Corchorus capsularis* and *C. olitorius.*
Lang-Lay Rope.—A rope in which the wires in each strand are twisted in the same direction as the strands in the rope.
Lay.—A term indicating the direction, or length, of twist of the wires and strands in a rope.
Live Load.—A load which is variable in distinction from a constant load.
Load Stress.—The stress produced by the load.
Locked-Wire Rope.—A rope with a smooth cylindrical surface, the outer wires of which are drawn to such shape that each one interlocks with the other and the wires are disposed in concentric layers about a wire core instead of in strands. Particularly adapted for haulage and rope-transmission purposes.

Manila.—The fiber of *Musa textilis*; Manila hemp.

Modulus of Elasticity.—The ratio between the amount of extension or compression of a material and the load producing this same extension or compression.

Plow Steel.—A select grade of steel of high tensile strength. First used in rope for plowing fields.

Proper Working Load.—The maximum load that a rope should be permitted to support under working conditions. (See *working load.*)

Regular-Lay Rope.—A rope in which the wires in each strand are twisted in opposite direction to the strands in the rope.

Round-Strand Rope.—A rope made of round twisted strands.

Running Rope.—A flexible rope that will pass through blocks and used for hoisting on shipboard. The term is also often used for any moving rope.

Sheave.—A wheel or pulley around or over which a rope passes.

Shroud Laid, or *Four-Strand, Rope* has four strands laid around a core.

Sisal.—A hemp. The fiber of the *Agave Sisalona.*

Socket.—A device fastened to the end of a rope by means of which the rope may be attached to its load. The socket may be opened or closed.

Splice.—The joining of two ends of rope by interweaving the strands.

Step Socket.—A special form of socket for use on locked-wire rope.

Stirrup.—An adjustable bale of a socket.

Stone Wire.—A term applied to wire smaller than No. 14 put up in 12-pound coils, which are about 8 inches inside diameter.

Strand.—A term applied to a varying number of wires or fibers twisted together. The strands in turn are twisted together, forming a rope.

Stress.—A force or combination of forces tending to change the shape of a body.

Strain.—A change of shape produced in a body. (Stress and strain are often used incorrectly as synonymous terms.)

Surging.—The flapping of a moving rope.

Swedish Iron.—A soft and comparatively pure iron.

Switch Rope.—A short length of rope fitted with a hook on one end and a link on the other, used for the switching of freight cars.

Tail-Rope.—(1) The rope that is used to draw the empties back into a mine in a tail-rope haulage system. (2) A rope attached beneath the cage when the cages are hoisting in balance.

Taper Rope.—A rope which has a gradually diminishing diameter from the upper to the lower end. The diameter of the rope is decreased by dropping one wire at a time at regular intervals. Both round and flat ropes may be made tapered, and such ropes are intended for deep-shaft hoisting with a view to proportioning the diameter of the rope to the load to be sustained at different depths.

Tensile Strength.—The stress required to break a rope by pulling it in two.

Thimble.—An oval iron ring around which a rope end is bent and fastened to form an eye.

Tiller Rope.—A very flexible wire rope composed of six small ropes, usually of seven-wire strands laid about a hemp core.

Tinned Rope.—Rope made of wires that have been coated with tin to protect them from corrosion.

Torsion.—The process of twisting a wire thereby showing its ductility.

Traction Rope.—A rope used for transmitting the power in a wire-rope tramway and to which the buckets are attached.

Transmission Rope.—A rope used for transmitting power.

Traveler.—A truck rolling along a suspended rope for supporting a load to be transported.

Turnbuckle.—A form of coupling so threaded or swiveled that by turning it the tension of a rope or rod may be regulated.

Ultimate Tensile Strength.—Same as tensile strength.

Universal Lay.—Another term for lang lay.

Whipping.—The flopping of a moving rope.

Wire Gauge.—Standard sizes or diameters for wire.

Wire Rope.—A rope whose strands are made of wires, twisted or woven together.

Working Load.—The maximum load that a rope can carry under the conditions of working without danger of straining. (Same as *proper working load.*)

Wrought Iron.—A comparatively pure and malleable iron.

Yarn.—Twisted fiber of which rope strands are made.

TABLE OF WIRE AND SHEET-METAL GAUGES.

Number of Gauge.	U. S. Standard Gauge for Sheet and Plate Iron and Steel. (Legal Standard.) Inch.	British Imperial Standard Wire Gauge. (Legal Standard in Great Britain.) Millim.	Birmingham Gauge. Inch.	American or Brown and Sharpe Gauge. Inch.	Roebling's Gauge. Inch.	Trenton Iron Co.'s Wire Gauge. Inch.	English Legal Standard. Inch.	Number of Gauge.
0000000	.5	12.7			.49		.500	0000000
000000	.469	11.78			.46		.464	000000
00000	.438	10.97			.43	.45	.432	00000
0000	.406	10.16	.454	.46	.393	.40	.4	0000
000	.375	9.45	.425	.40964	.362	.36	.372	000
00	.344	8.84	.38	.3648	.331	.33	.348	00
0	.313	8.23	.34	.32486	.307	.305	.324	0
1	.281	7.62	.3	.2893	.283	.285	.3	1
2	.266	7.01	.284	.25763	.263	.265	.276	2
3	.25	6.4	.259	.22942	.244	.245	.252	3
4	.234	5.89	.238	.20431	.225	.225	.232	4
5	.219	5.38	.22	.18194	.207	.205	.212	5
6	.203	4.88	.203	.16202	.192	.19	.192	6
7	.188	4.47	.18	.14428	.177	.175	.176	7
8	.172	4.06	.165	.12849	.162	.16	.16	8
9	.156	3.66	.148	.11443	.148	.145	.144	9
10	.141	3.26	.134	.10189	.135	.13	.128	10
11	.125	2.95	.12	.09074	.12	.1175	.116	11
12	.109	2.64	.109	.08081	.105	.105	.104	12
13	.094	2.34	.095	.07196	.092	.0925	.092	13
14	.078	2.03	.083	.06408	.08	.08	.08	14
15	.07	1.83	.072	.05707	.072	.07	.072	15
16	.0625	1.63	.065	.05082	.063	.061	.064	16
17	.0563	1.42	.058	.04526	.054	.0525	.056	17
18	.05	1.22	.049	.0403	.047	.045	.048	18
19	.0438	1.01	.042	.03589	.041	.04	.04	19
20	.0375	.91	.035	.03196	.035	.035	.036	20
21	.0344	.81	.032	.02846	.032	.031	.032	21
22	.0313	.71	.028	.02535	.028	.028	.028	22
23	.0281	.61	.025	.02257	.025	.025	.024	23
24	.025	.56	.022	.0201	.023	.0225	.022	24
25	.0219	.51	.02	.0179	.02	.02	.02	25
26	.0188	.45	.018	.01594	.018	.018	.018	26
27	.0172	.42	.016	.01419	.017	.017	.0164	27
28	.0156	.38	.014	.01264	.016	.016	.0148	28
29	.0141	.35	.013	.01126	.015	.015	.0136	29
30	.0125	.31	.012	.01002	.014	.014	.0124	30
31	.0109	.29	.01	.00893	.0135	.013	.0116	31
32	.0101	.27	.009	.00795	.013	.012	.0108	32
33	.0094	.25	.008	.00708	.011	.011	.01	33
34	.0086	.23	.007	.0063	.01	.01	.0092	34
35	.0078	.21	.005	.00561	.0095	.0095	.0084	35
36	.007	.19	.004	.005	.009	.009	.0076	36
37	.0066	.17		.00445	.0085	.0085	.0068	37
38	.0063	.15		.00396	.008	.008	.006	38
39		.13		.00353	.0075	.0075	.0052	39
40		.12		.00314	.007	.007	.0048	40
41		.11					.0044	41
42		.10					.004	42
43		.09					.0036	43
44		.08					.0032	44
45		.07					.0028	45
46		.06					.0024	46
47		.05					.002	47
48		.04					.0016	48
49		.03					.0012	49
50		.025					.001	50

STRESS IN HOISTING ROPES ON INCLINED PLANES OF VARIOUS DEGREES.

(*From "Wire-Rope Transportation," published by Trenton Iron Co.*)

The following table is based upon an allowance of 40 lb. per ton for rolling friction, but there will be an additional stress due to the weight of the rope and inclination of the plane.

Rise per 100 Ft. Horizontal. Ft.	Angle of Inclination.	Stress in Lb. per Ton of 2,000 Lb.	Rise per 100 Ft. Horizontal. Ft.	Angle of Inclination.	Stress in Lb. per Ton of 2,000 Lb.
5	2° 52′	140	105	46° 24′	1,484
10	5° 43′	240	110	47° 44′	1,516
15	8° 32′	336	115	49° 00′	1,535
20	11° 10′	432	120	50° 12′	1,573
25	14° 03′	527	125	51° 21′	1,597
30	16° 42′	613	130	52° 26′	1,620
35	19° 18′	700	135	53° 29′	1,642
40	21° 49′	782	140	54° 28′	1,663
45	24° 14′	860	145	55° 25′	1,682
50	26° 34′	933	150	56° 19′	1,699
55	28° 49′	1,003	155	57° 11′	1,715
60	30° 58′	1,067	160	58° 00′	1,730
65	33° 02′	1,128	165	58° 47′	1,744
70	35° 00′	1,185	170	59° 33′	1,758
75	36° 53′	1,238	175	60° 16′	1,771
80	38° 40′	1,287	180	60° 57′	1,782
85	40° 22′	1,332	185	61° 37′	1,794
90	42° 00′	1,375	190	62° 15′	1,804
95	43° 32′	1,415	195	62° 52′	1,813
100	45° 00′	1,450	200	63° 27′	1,822

RELATIVE EFFECTS OF VARIOUS SIZED SHEAVES OR DRUMS ON THE LIFE OF WIRE ROPES.

Mine officials and other users of wire ropes have often felt the want of a table or set of tables that would enable them to determine at a glance what effect the use of various sized sheaves would have on various sized ropes. The following tables have been specially prepared for the Coal and Metal Miner's Pocketbook by Mr. Thomas E. Hughes, of Pittsburg, Pa.

CAST-STEEL ROPES FOR INCLINES.

MADE OF 6 STRANDS OF 7 WIRES EACH, LAID AROUND A HEMP CORE.

Diameter of Rope. Inches.	Diameters of Sheaves or Drums in Feet, Showing Percentages of Life for Various Diameters.						
	100%	90%	80%	75%	60%	50%	25%
$1\frac{1}{2}$	16.00	14.00	12.00	11.00	9.00	7.00	4.75
$1\frac{3}{8}$	14.00	12.00	10.00	8.50	7.00	6.00	4.50
$1\frac{1}{4}$	12.00	10.00	8.00	7.25	6.00	5.50	4.25
$1\frac{1}{8}$	10.00	8.50	7.75	7.00	6.00	5.00	4.00
1	8.50	7.75	6.75	6.00	5.00	4.50	3.75
$\frac{7}{8}$	7.75	7.00	6.25	5.75	4.50	3.75	3.25
$\frac{3}{4}$	7.00	6.25	5.50	5.00	4.25	3.50	2.75
$\frac{5}{8}$	6.00	5.25	4.50	4.00	3.25	3.00	2.50
$\frac{1}{2}$	5.00	4.50	4.00	3.50	2.75	2.25	1.75

NOTE.—We do not publish a table of iron ropes for inclines, as the use of iron ropes for this purpose has been generally abandoned, steel ropes being far more satisfactory and economical.

CAST-STEEL HOISTING ROPES.

MADE OF 6 STRANDS OF 19 WIRES EACH, LAID AROUND A HEMP CORE.

Diameter of Rope. Inches.	Diameters of Sheaves or Drums in Feet, Showing Percentages of Life for Various Diameters.						
	100%	90%	80%	75%	60%	50%	25%
$1\frac{1}{2}$	14.00	12.00	10.00	8.50	7.00	6.00	4.50
$1\frac{3}{8}$	12.00	10.00	8.00	7.00	6.00	5.25	4.25
$1\frac{1}{4}$	10.00	8.50	7.50	6.75	5.50	5.00	4.00
$1\frac{1}{8}$	9.00	7.50	6.50	5.50	5.00	4.50	3.75
1	8.00	7.00	6.00	5.50	4.50	4.00	3.50
$\frac{7}{8}$	7.50	6.75	5.75	5.00	4.25	3.50	3.00
$\frac{3}{4}$	5.50	4.50	4.00	3.75	3.25	3.00	2.25
$\frac{5}{8}$	4.50	4.00	3.75	3.25	3.00	2.50	2.00
$\frac{1}{2}$	4.00	3.00	3.00	2.75	2.25	2.00	1.50
$\frac{3}{8}$	3.00			2.00		1.50	

IRON HOISTING ROPES.

MADE OF 6 STRANDS OF 19 WIRES EACH, LAID AROUND A HEMP CORE.

Diameter of Rope. Inches.	Diameters of Sheaves or Drums in Feet, Showing Percentages of Life for Various Diameters.						
	100%	90%	80%	75%	60%	50%	25%
$1\frac{1}{2}$	12.00	11.00	9.00	7.50	6.00	5.00	3.00
$1\frac{3}{8}$	10.00	9.00	7.50	7.00	5.25	4.75	4.00
$1\frac{1}{4}$	9.00	7.75	6.50	5.75	4.50	4.00	3.50
$1\frac{1}{8}$	8.00	6.75	5.50	5.00	4.25	3.50	3.00
1	6.75	6.00	5.00	4.75	4.00	3.25	2.75
$\frac{7}{8}$	6.75	6.00	5.00	4.50	4.00	3.00	2.50
$\frac{3}{4}$	5.00	4.75	4.00	3.75	3.00	2.75	2.00
$\frac{5}{8}$	4.50	3.75	3.25	3.00	2.75	2.25	1.75
$\frac{1}{2}$	3.50	3.25	3.00	2.75	2.00	1.50	1.00
$\frac{3}{8}$	3.00		2.00			1.25	1.00

Wire rope is as pliable as new hemp rope of the same strength; the former will therefore run on the same sized sheaves and pulleys as the latter. But the greater the diameter of the sheaves, pulleys, and drums, the longer wire rope will last. In the construction of machinery for wire rope, it will be found good economy to make the drums and sheaves as large as possible.

The tables of wire-rope manufacturers give "proper diameters of drum or sheave" at from 50 to 65 times the rope diameter; but the expression would more properly be the "minimum admissible diameter." For ordinary service, by using sheaves and drums from 75 to 100 times the diameter of the rope, the average life of hoisting ropes would be materially lengthened. For rapid hoisting, during which abnormal strains are most likely to occur, or where a low factor of safety is employed, a sheave diameter of 150 times that of the rope is to be recommended.

Experience has demonstrated that the wear increases with the speed. It is therefore better to increase the load than the speed. Wire rope is manufactured either with a wire or a hemp center. The latter is more pliable than the former, and will wear better where there is short bending.

Wire rope must not be coiled or uncoiled like hemp rope. When mounted on a reel, the latter should be mounted on a spindle or flat turntable to pay off the rope. When forwarded in a small coil, without reel, roll it over the ground like a wheel, and run off the rope in that way. All untwisting or kinking must be avoided.

EXTRA STRAIN ON A HOISTING ROPE WITH A FEW INCHES OF SLACK CHAIN

Dynamometer Tests.	Tons.	Cwts.
First Test		
Empty cage lifted gently	1	16
Empty cage with 2½ inches slack chain	2	10
Empty cage with 6 inches slack chain	4	0
Empty cage with 12 inches slack chain	5	10
Second Test		
Cage and four empty cars weighed by machine	2	17
Cage and four empty cars lifted gently	3	0
Cage and four empty cars with 3 inches slack chain	5	0
Cage and four empty cars with 6 inches slack chain	5	10
Cage and four empty cars with 12 inches slack chain	7	0
Third Test		
Cage and full cars weighed by machine	5	1
No. 1, lifted gently	5	1
No. 2, lifted gently	5	3
No. 1, with 3 inches slack chain	8	10
No. 2, with 3 inches slack chain	8	10
No. 1, with 6 inches slack chain	10	10
No. 2, with 6 inches slack chain	11	10
No. 1, with 9 inches slack chain	12	10
No. 2, with 9 inches slack chain	11	10

WIRE-ROPE CALCULATIONS.

The *working load*, also called the proper working load, is the maximum load that a rope should be permitted to support under working conditions. The stress on a rope to which a load is attached, and which bends over a sheave, is made up of two parts: (1) That due to the load on the rope, known as the load stress; (2) that due to the bending of the rope about a sheave or drum, known as the bending stress. That is, if

S = total safe stress;
S_b = bending stress;
S_l = load stress;
$S = S_b + S_l$ and $S_l = S - S_b$.

The total stress must not equal the elastic limit of the material composing the rope and is usually taken as from one-third to one-fourth the approximate breaking stress.

It is only quite recently that account has been taken of this second stress in wire-rope problems, and it is not, as yet, by any means universal practice to consider it in calculating the size of rope needed for a given purpose.

If we have a given weight to hoist with a wire rope, the proper size of rope to use may be taken directly from the tables on pages 120, 121, 122, but this does not take account of the bending stress, except by allowing for it in the factor of safety assumed.

A second method calculates the bending stress.

The following formulas and the diagram based on them, given on page 125, are given by Mr. E. T. Sederholm, former chief engineer for Fraser & Chalmers, and will be found in the hoisting-engine catalogue of the Allis-Chalmers Co.

The general formula for the bending stress is

$$S_b = \frac{E\,a\,A}{D};$$

in which S_b = bending stress;
E = modulus of elasticity;
a = diameter of each wire;
D = diameter of drum or sheave;
A = total area of the wire cross-section, in inches.

For a rope of 19 wires to the strand the diameter of each wire is about one-fifteenth (exactly $\frac{100}{1552}$) of the diameter of the rope. That is, if d = diameter of rope, $a = \frac{d}{15.52}$; and by substituting this in the above formula $S_b = \frac{E\,A\,d}{15.52\,D}$.

The modulus of elasticity for the different kinds of wire is given different values by different authorities. Mr. Sederholm uses 29,400,000 in his formula and diagram, and Mr. Hewitt 28,500,000, the same modulus being used for the different materials of which ropes are made.

The cross-section of metal A in a wire rope is approximately $.4\,d^2$, or it may be more accurately calculated by multiplying the cross-section of each wire, as given by a wire table, by the number of wires in the rope.

Find the bending stress in a 19-wire, cast-steel hoisting rope 2 in. in diameter, winding on an 8-ft. drum, if $A = .4\,d^2$, and $E = 29{,}400{,}000$,

$$S_b = \frac{29{,}400{,}000 \times 2^3 \times .4}{10 \times 15.52 \times 96 \times 2{,}000} = 31.51 \text{ tons.}$$

The approximate breaking stress for such a rope is 124 tons, and if we assume a factor of 3, $\frac{124}{3} = 41+$ tons for the safe working stress, and $41 - 32 = 9$ tons, for the safe lifting load under the given conditions.

The diagram given on page 125 is based on the above formula.

Mr. Wm. Hewitt, of the Trenton Iron Co., has given a similar but more complicated formula for the bending stress, which is supposed to give somewhat more accurate results, as he has introduced terms which allow for the actual radius of the bend at the outside fiber of the rope, while the Sederholm formula assumes the radius of the bend to be the radius of the sheave.

Mr. Hewitt's formula is as follows:

$$S_b = \frac{E\,A}{2.06\,\frac{R}{d} + C}$$

in which S_b = bending stress, in pounds;
E = modulus of elasticity (28,500,000);
A = aggregate area of wires, in square inches;
R = radius of drum or sheave, in inches;
d = diameter of individual wires, in inches;
C = a constant depending on number of wires in strands.

The values of d and C are:

7-Wire Rope	19-Wire Rope
$d = \frac{1}{9}$ diameter of rope	$d = \frac{1}{15}$ diameter of rope
$C = 9.27$	$C = 15.45$

For 12-wire and 16-wire ropes the values are intermediate in proportion to the number of wires In the case of ropes having strands composed of different sizes of wires, take the larger of the outer layer for the value of d.

Mr. Hewitt assumes one-third of the approximate breaking stress as the maximum safe stress and uses 28,500,000 for the modulus of elasticity.

If the problem given under the Sederholm formula is worked out by the Hewitt formula the safe working load will be $11\frac{1}{2}$ tons, while the table on pages 120 and 121 gives 24.8 tons.

The Sederholm diagram on page 125 gives for a load of 24.8 tons a sheave between 16 and 17 ft. diameter, the Sederholm formula gives a sheave of 15 ft. in diameter, while the table on pages 120 and 121 gives 8 ft. It is evident that there is a wide difference of opinion among the wire-rope authorities and a good opportunity for experimental work along this line.

In using the Sederholm or Hewitt formulas there are two unknown quantities, the diameter of the rope d and the diameter D or radius R of the drum. d varies inversely as D, that is, for a given load the smaller d is taken the larger D must be to give the same conditions of safety.

If we could assume a certain ratio between S_b and S_l in the formula $S = S_b + S_l$ the problem could be easily solved, but an examination of this ratio in a number of cases where good results have been obtained from hoisting ropes shows this ratio to vary from $\frac{S_l}{S_b} = 1$ to $\frac{S_l}{S_b} = \frac{2}{5}$. In the transmission of power by wire ropes, Mr. Hewitt assumes $\frac{S_l}{S_b} = \frac{1}{2}$, but this relation will scarcely hold in a hoisting problem, and the above problem must be solved by the cut-and-try method.

Wear of Wire Ropes.—The deterioration of wire ropes may be either external or internal, and may be due (1) to abrasion, due to the rubbing of the outside surface of the rope against other objects, or to the internal chafing of the wires composing the strands against one another; (2) to injury from overloading, to shock due to sudden starting of the load, or to repeated bendings about too sharp angles or over sheaves or rollers of too small a diameter for the size of the rope; (3) to rust or corrosion of the wire from acid waters, or to decay of the hemp cores.

As a result of abrasion, the wires in a rope are either flattened or torn apart. With properly designed drums and head-frame and properly placed sheaves, a hoisting rope is but slightly abraded, and the wear is due chiefly to bending or to overloading. A haulage rope is subjected to constant abrasion in passing over rollers and sheaves and from dragging along the bottom and sides of the haulage ways and from the grips. It is also often subject to severe shocks and abrasion from the lashing or vibration when the winding engine starts.

The wear and tear on a rope increases as its velocity is increased; hence, conditions permitting, it is better to increase the output by increasing the load within allowable limits rather than by increasing the velocity of the rope.

Inspection of Ropes.—The life of a hoisting rope depends not only on its quality, but also on the conditions under which it is used and on the carefulness of the engineer in handling the load. A rope should be inspected often and at regular intervals. At some mines the hoisting ropes are inspected every morning before lowering the men. The cage is slowly lowered and then raised, each rope being carefully examined by an inspector to detect any broken wires. Particular attention should be given to the part of the rope where it is attached to the socket at the cage, as this part is more subject to corrosion and sharp bending than any other. When the core fails at any point the rope should be discarded at once, as the wires are likely to kink and break internally as the rope passes over the sheave. At some mines hoisting ropes are discarded at regular intervals, whether they show wear or not. Haulage ropes do not require as frequent examination, and are not discarded as quickly, as hoisting ropes, as much less in the way of life and property is dependent on them. A new piece of loose hemp rope with one turn round the haulage rope and each end held firmly while the rope is run will indicate loose wire ends.

Lubrication of Ropes.—Mine water has a very corrosive action on wire ropes, and a rope will soon be destroyed unless the water is prevented from coming in contact with the metal of the rope. To avoid this corrosive action tar, black oil, or some lubricating preparation is applied to the rope, but any lubricant used must be free from acids or other substances that would corrode the wire.

For hoisting ropes, one bushel of freshly slacked lime to one barrel of pine or coal tar makes a good lubricant; with pine tar, which contains no acid, tallow may be used instead of lime. Another mixture contains tar, summer oil, axle grease, and a little pulverized mica, mixed to such a consistency that it will penetrate thoroughly between the wires and will not dry nor strip off. The lubricant should not be thick enough to render difficult the thorough inspection of the rope, and all lubricants of this nature should be used sparingly after the first application, as the rope should be kept clean and free from grit. Graphite is also used for the purpose. Lubricants may be applied by running the engine slowly and allowing the rope to pass through a bunch of waste saturated with lubricant, by rubbing the lubricant into the rope by means of a brush, or by pouring the oil into the groove of the sheave as the rope is run slowly back and forth. A new hoisting rope should be passed through a bath of hot lubricant and thus be thoroughly lubricated.

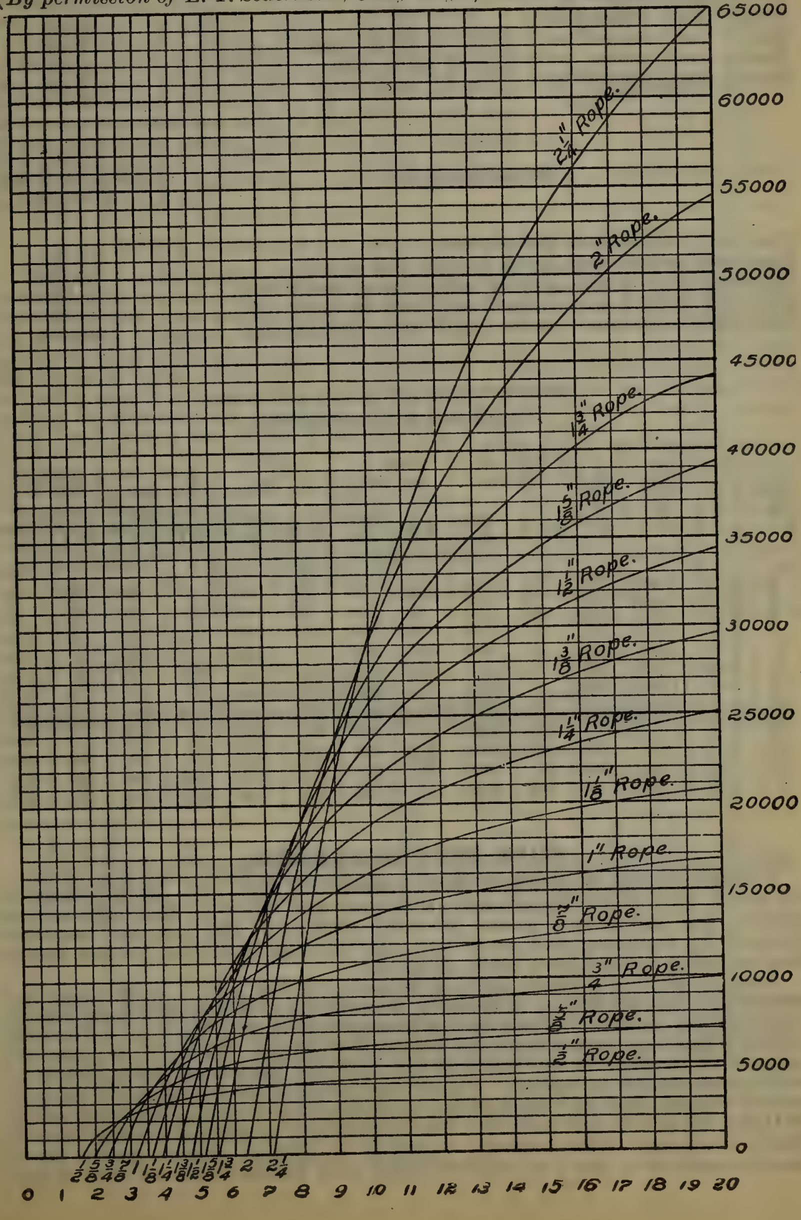
Haulage ropes are not usually lubricated as thoroughly as hoisting ropes on account of the grease causing slipping of grips and gathering of dirt and dust, but they can be treated with raw linseed oil thickened with lamp black boiled with an equal portion of pine tar, and the mixture applied while hot. Ordinary black oil, such as is used to oil mine cars and hoisting ropes, can be used on haulage ropes where no friction grips are employed. These mixtures, if fluid, can be poured on the rope as it is run over the sheave, or applied from a leather-lined box filled with oil. Patent lubricants known as *cable shields* or *rope fillers*, which fill the interstices between the strands, are often used on tail and main ropes.

PROPER WORKING LOAD

For steel hoisting ropes, made with 19 wires to the strand, when used on drums of different diameters. Total strain of wire rope, including bending strain and the strain due to load, assumed at 50,000 lb. per sq. in. of actual steel section. d = diameter of rope in in.; D = diameter of drum in in.; S = strain per sq. in. due to bending; L = proper working load in pounds.

$$S = 1{,}894{,}000 \times \frac{d}{D}. \qquad L = 20{,}000\, d^2 - 757{,}600 \times \frac{d^3}{D}.$$

(*By permission of E. T. Sederholm, Chief Engr.; Fraser & Chalmers, Chicago.*)



Starting Strain on Hoisting Rope.—In selecting a hoisting rope, due allowance must be made for the shock and extra strain imposed on the rope when the load is started from rest. Experiments made by placing a dynamometer between the rope and the cage have shown that starting stress may be from two to three times the actual load.

Experiment 1.	Strain in Rope. Pounds.
Empty cage, lifted gently	4,030
Empty cage, started with 2½ in. of slack rope	5,600
Empty cage, started with 6 in. of slack rope	8,950
Empty cage, started with 12 in. of slack rope	12,300

Experiment 2.	Strain in Rope. Pounds.
Cage and loaded cars, as weighed	11,300
Cage and loaded cars, lifted slowly and gently	11,525
Cage and loaded cars, started with 3 in. of slack rope	19,025
Cage and loaded cars, started with 6 in. of slack rope	24,625
Cage and loaded cars, started with 9 in. of slack rope	26,850

Horsepower of Manila Ropes.
(*Link-Belt Engineering Co.*)

Diam. of Rope.	Weight per Foot.	Breaking Strain.	Working Strain.	1,000 Ft. per Min.		2,000 Ft. per Min.		3,000 Ft. per Min.		4,000 Ft. per Min.		5,000 Ft. per Min.	
				H. P.	Tens. Wt.	H. P.	Tens. Wt.	H. P.	Tens. Wt.	H. P.	Tens. Wt.	H. P.	Tens. Wt.
⅝	0.15	4,000	121	2¼	90	4½	90	6¼	80	7½	80	8½	70
¾	0.18	5,000	151	2¾	110	5½	110	7¾	100	9¾	100	10¾	90
⅞	0.27	7,500	227	4¼	170	8¼	170	11¾	160	14½	150	16	130
1	0.33	9,000	272	5	200	10	200	14	180	17¼	170	19	150
1⅛	0.45	12,250	371	7	280	13½	270	19	250	23½	230	26	210
1¼	0.50	14,000	424	8	320	15½	310	22	290	27	270	29½	240
1⅜	0.65	18,062	547	10¼	410	20	400	28¼	370	34¾	350	38½	310
1½	0.73	20,250	613	11½	460	22	440	31½	420	39	390	43½	350
1⅝	0.82	25,000	760	14¼	570	27¾	550	39½	520	49	490	55½	448
1¾	1.08	30,250	916	17	680	33½	660	47¼	630	58¼	580	64¾	520
2	1.27	36,000	1,000	20½	810	40	790	56½	740	69¼	670	77½	620

WIRE-ROPE FASTENINGS.

Thimble spliced, in ordinary style, is shown in Fig. 1 (*a*). In this method, the wires, after being frayed out at the end and the rope bent around the thimble, are laid snugly about the main portion of the rope and securely fastened by wrapping with stout wire, the extreme ends that project below this wrapping being folded back, as shown.

Another style of thimble splicing is shown in Fig. 1 (*b*). In this case the strands are interlocked as in splicing, and the joint is wrapped with wire as in the former method. The socket fastening is shown in Fig. 1 (*c*). The hole in which the rope end is fastened is conical in shape. The rope is generally secured by fraying out the wires at the end, the interstices being filled up with spikes driven in tightly. The whole is finally cemented by pouring in molten Babbitt metal. This makes a much neater fastening than either of those shown in (*a*) and (*b*), but it does not possess anything like as much strength. The thimble possesses a serious disadvantage; it is usually made of a piece of curved metal bent around into an oval shape,

as shown in (*a*) and (*b*), with the groove, in which the rope lies, outside, the ends coming together in a sharp point. When weight is placed on the rope, the strain on the thimble is apt to cause one end to wedge itself beyond or past the other, and with its sharp edge it cuts the strands in the splice. Mr. William Hewitt, of Trenton, N. J., while testing the strength of wire ropes, discovered this tendency, and experimented with sockets with the idea of devising some method of fastening the rope securely in the socket. He found that by adopting the following plan he secured good results:

The wires, after being frayed out at the end, were bent upon themselves in hook fashion, the prongs of some being longer than others, so that the bunch would conform to the conical aperture of the socket, and the melted Babbitt metal was finally run in as usual. The rope was subjected to a strain of over 129,000 lb., and the wires in the socket were unaffected. The simplicity of this method commends itself to practical men.

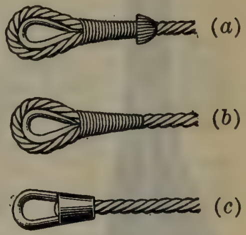
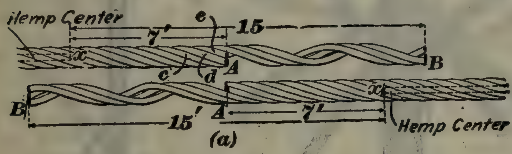


FIG. 1.

RAPID METHOD OF SPLICING A WIRE ROPE.*

The only tools needed are a cold cutter and hammer for cutting and trimming the strands, and two needles 12 in. long, made of good steel and tapered ovally to a point. Cut off the ends of the ropes to be spliced and unlay three adjacent strands of each back 15 ft.; cut out the hemp center to this point and relay the strands for 7 ft. and cut them off. Pull the ropes by each other until they have the position shown in Fig. 2 (*a*), cut off *a* and *d*′, *b* and *c*′, Fig. 2 (*b*), making their lengths approximately 10 and 12½ ft., respectively, measured from the point where the hemp centers were cut. Place the ropes together, Fig. 2 (*b*); unlay *e*, *d*, *c*, Fig. 2 (*a*), keeping the strands together, and follow with *e*′, *d*′, *c*′, Fig. 2 (*b*). Similarly, unlay *f*′, *a*′, *b*′, Fig. 2 (*b*), and follow with *f*, *a*, *b*, until the rope appears as in Fig. 2 (*c*). Next run the strands into the middle of the rope. To do this, cut off the end of the strand *e*′, Fig. 2 (*c*), so that when it is put in place it will just reach to the end *x* of the hemp core, and then push the needle *A*, Fig. 2 (*c*), through the rope from the under side, leaving two strands at the front of the needle, as shown. Push the needle *B* through from the upper side and as close to the needle *A* as possible, leaving the strands *e* and *e*′ between them; place the needle *A* on the knee and turn the needle *B* around with the coil of the rope, and force the strand *e*′ into the center of the rope. Repeat this



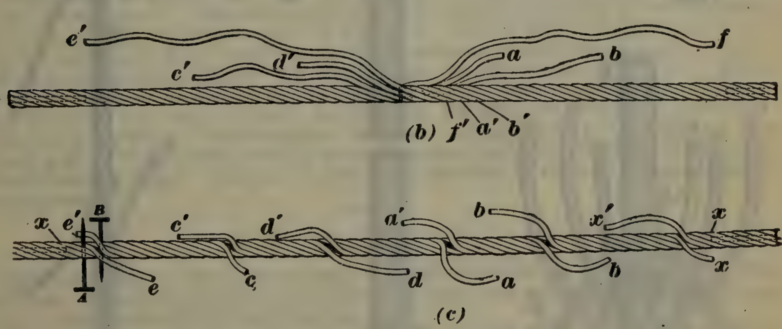


FIG. 2.

* W. H. Morris, "Mines and Minerals," September, 1898.

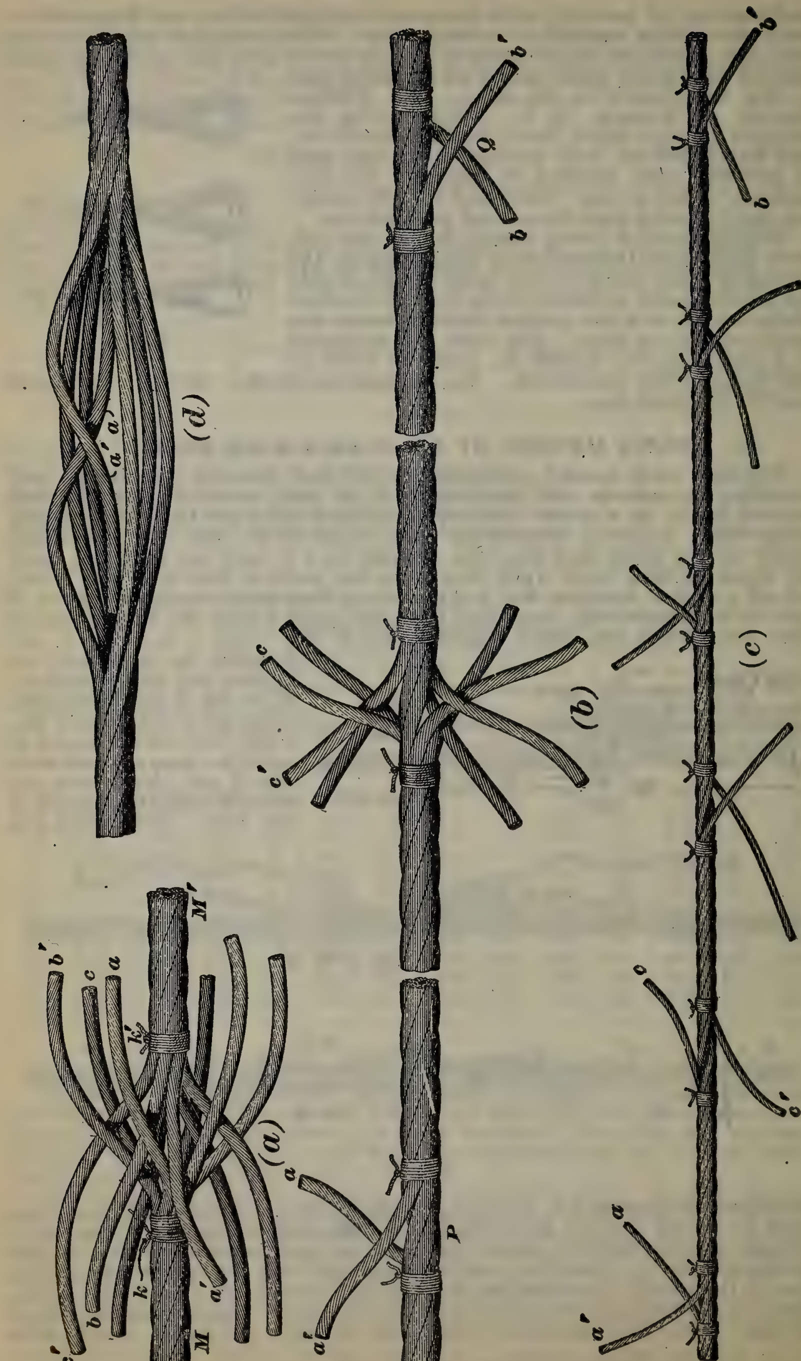


FIG. 3.

operation with the other ends and cut them off so that the ends coming together in the center of the rope will butt against each other as nearly as possible.

ORDINARY LONG SPLICE.

Tools Required.—One pair wire nippers, for cutting off strands; one pair pliers, for pulling through and straightening ends of strands; two marlinespikes, one round and one oval, for opening strands; one knife to cut hemp center; two clamps, to untwist rope to insert ends of strands, or, in place of them, two short hemp-rope slings, with a stick for each as a lever; a wooden mallet and some rope twine. Also, a bench and vise are handy.

The length of the splice depends on the size of the rope. The larger ropes require the longer splices. The splice of ropes from $\frac{5}{8}$ in. to $\frac{7}{8}$ in. in diameter should not be less than 20 ft.; from $\frac{7}{8}$ in. to $1\frac{1}{8}$ in., 30 ft.; and from $1\frac{1}{8}$ in. up, 40 ft.

To splice a rope, tie each end with a piece of cord at a distance equal to one-half the length of the splice, or 10 ft. back from the end, for a $\frac{5}{8}''$ rope, after which unlay each end as far as the cord. Then cut out the hemp center, and bring the two ends together as close as possible, placing the strands of the one end between those of the other, as shown in Fig. 3 (a). Now remove the cord k from the end M of the rope, and unlay any strand, as a, and follow it up with the strand of the other end M' of the rope that corresponds to it, as a', Fig. 3 (a). About 6 in. of a are left out, and a is cut off about 6 in. from the rope, thus leaving two short ends, as shown at P in Fig. 3 (b), which must be tied for the present by cords as shown. The cord k should again be wound around the end M of the rope, Fig. 3 (a), to prevent the unraveling of the strands; after which remove the cord k' on the other or M' end of the rope, and unlay the strand b; follow it up, as above, with the strand b', leaving the ends out, and tying them down for the present, as before described in the case of strands a and a', see Q, Fig. 3 (b); also, replace the cord k' for the same purpose as stated above. Now, again remove the cord k and unlay the next strand, as c, Fig. 3 (a), and follow it up with c', stopping, however, this time within 4 ft. of the first set. Continue this operation with the remaining 6 strands, stopping 4 ft. short of the preceding set each time. The strands are now in their proper places, with the ends passing each other at intervals of 4 ft., as shown in Fig. 3 (c). To dispose of the loose ends, clamp the rope in a vise at the left of the strands a and a', Fig. 3 (c), and fasten a clamp to the rope at the right of these strands; then remove the cords tied around the rope that hold these two strands down; after which turn the clamp in the opposite direction to which the rope is twisted, thereby untwisting the rope, as shown in Fig. 3 (d). The rope should be untwisted enough to allow its hemp core to be pulled out with a pair of nippers. Cut off 24 in. of the hemp core, 12 in. at each side from the point of intersection of the strands a and a', and push the ends of the strands in their place, as shown in Fig. 3 (d). Then allow the rope to twist up to its natural shape, and remove the clamps. After the rope has been allowed to twist up, the strands tucked in generally bulge out somewhat. This bulging may be reduced by lightly tapping the bulged part of the strands with a wooden mallet, which will force their ends farther into the rope. Proceed in the same manner to tuck in the other ends of the strands.

CHAINS.

The links of iron chains are usually made as short as is consistent with easy play, so as to make them less liable to kink, and also to prevent bending when wound around drums, sheaves, etc.

The weight of close-link chain is about three times the weight of bar from which it is made, for equal lengths.

Karl von Ott, comparing weight, cost, and strength of three materials, hemp, iron wire, and chain iron, concludes that the proportion between cost of hemp rope, wire rope, and chain is as 2 : 1 : 3, and that, therefore, for equal resistances, wire rope is only half the cost of hemp rope, and a third of cost of chains.

Chains of warranted superior iron will stand 25% more strain before breaking. The report of the U. S. Test Board, 1881, shows that the ultimate strength of chains may be taken at 1.6 that of the iron from which the links are made.

The strength of chains varies, owing to the nature of the iron from which they are made, and their mechanical construction. The following table is approximately correct for ordinary iron chains:

TABLE OF WEIGHT AND STRENGTH OF CHAINS.

Diameter of Rod of Which the Links Are Made. Inches.	Weight of Chain per Running Foot. Pounds.	Working Strength. Tons.	Breaking Strain. Tons.	Diameter of Rod of Which the Links Are Made. Inches.	Weight of Chain per Running Foot. Pounds.	Working Strength. Tons.	Breaking Strain. Tons.
$\frac{3}{16}$	.325	.19	.773	$\frac{7}{8}$	7.10	4.40	16.80
$\frac{1}{4}$	.579	.36	1.37	$\frac{15}{16}$	8.14	5.00	19.32
$\frac{5}{16}$	.904	.45	2.14	1	9.26	5.71	22.00
$\frac{3}{8}$	1.30	.85	3.09	$1\frac{1}{8}$	11.70	7.23	26.44
$\frac{7}{16}$	1.78	1.09	4.20	$1\frac{1}{4}$	14.50	9.00	32.64
$\frac{1}{2}$	2.31	1.43	5.50	$1\frac{3}{8}$	17.50	10.80	39.42
$\frac{9}{16}$	2.93	1.80	6.96	$1\frac{1}{2}$	20.80	13.00	47.00
$\frac{5}{8}$	3.62	2.23	8.58	$1\frac{5}{8}$	24.40	15.24	55.14
$\frac{11}{16}$	4.38	2.70	10.39	$1\frac{3}{4}$	28.40	17.65	63.97
$\frac{3}{4}$	5.21	3.21	12.36	$1\frac{7}{8}$	32.60	20.27	73.44
$\frac{13}{16}$	6.11	3.80	14.42	2	37.00	23.10	83.55

HYDROSTATICS.

Hydrostatics treats of the equilibrium of liquids, and of their pressures on the walls of vessels containing them; the science depends on the way in which the molecules of a liquid form a mass under the action of gravity and molecular attraction, the latter of which is so modified in liquids as to give them their state of liquidity. While the particles of a liquid cohere, they are free to slide upon one another without the least apparent friction; and it is this perfect mobility that gives them the mechanical properties considered in hydrostatics.

The fundamental property may be thus stated: *When a pressure is exerted on any part of the surface of a liquid, that pressure is transmitted undiminished to all parts of the mass, and in all directions.* This is a physical axiom, and on it are based nearly all the principles of hydrostatics.

Equilibrium of Liquids.—This is a property of liquids that can be easily demonstrated, and examples are frequently seen. Thus, if two barrels are connected at the bottom with a pipe, and water is poured in one until it reaches within a foot of the top, the water in the other will be found to have attained the same height.

Pressure of Liquids on Surfaces.—The general proposition on this point is as follows: *The pressure of a liquid on any surface immersed in it is equal to the weight of a column of the liquid whose base is the surface pressed, and whose height is the perpendicular depth of the center of gravity of the surface below the surface of the liquid.* The pressure thus exerted is independent of the shape or size of the vessel or cavity containing the liquid.

The pressure of a liquid against any point of any surface, either curved or plane, is always perpendicular to the surface at that point.

At any given depth the pressure of a liquid is equal in every direction, and is in direct proportion to the vertical depth below the surface.

The weight of a cubic foot of fresh water, at ordinary temperature of the atmosphere, that is, from 32° F. to 80° F., is usually assumed at 62.5 lb. This is a trifle more than the actual weight, but is sufficiently close for purposes of calculation.

To Find the Pressure Exerted by Quiet Water Against the Side of a Gangway or Heading.—Multiply the area of the side in square feet by the perpendicular distance from the surface of the water to a point equidistant between the top and bottom of the submerged heading or gangway, and multiply the product by 62.5. The result will be the pressure in pounds, exclusive of atmospheric pressure. This latter need not be considered in ordinary mining work.

EXAMPLE.—If an abandoned colliery, opened by a slope on a pitch of 25° and 100 yd. long, is allowed to fill with water, what is the average pressure exerted on each square foot of the lower rib of the gangway, assuming that the gangways were driven dead level, and that the length of the slope was measured to a point on the lower rib equidistant between top and bottom of gangway.

We here have a perpendicular height of water = 300 × sine of 25° = 126.78 ft. Then, the pressure on each square foot of the lower rib of gangway = 126.78 × 62.5 lb., or the weight of 1 cu. ft., or a pressure on each square foot of surface of 7,923.75 lb., or over $3\frac{1}{2}$ gross tons. The total pressure exerted along the gangway may readily be found by multiplying the 7,923.75 lb. by the number of square feet of the lower rib against which it rests.

To find the total pressure of quiet water against and perpendicular to any surface whatever, as a dam, embankment, or the bottom, side or top of any containing vessel, water pipe, etc., no matter whether said surface be vertical, horizontal, or inclined; or whether it be flat or curved; or whether it reach to the surface of the water or be entirely below it:

Multiply the area, in square feet, of the surface pressed, by the vertical depth in feet of its center of gravity below the surface of the water, and this product by 62.5. The result will be the pressure in pounds.

Thus, assuming that in the annexed three figures the depth of water in each dam is 12 ft., and the wall or embankment is 50 ft. long, then in Fig. 1 the total pressure will equal 12 × 50 × 6 × 62.5 = 225,000 lb.

In Figs. 2 and 3 the walls or embankments, being inclined, expose a greater surface to pressure, say 18 ft. from A to B. Then the total pressure equals 18 × 50 × 6 × 62.5 = 337,500 lb.

Now, the results obtained are the *total* pressures without regard to direction.

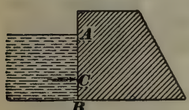


FIG. 1.

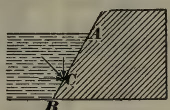


FIG. 2.

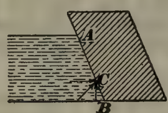


FIG. 3.

In Fig. 1 the total pressure calculated, or 225,000 lb., is horizontal, tending either to overturn the wall or make it slide on its base. The center of pressure is at C, or one-third of the vertical depth from the bottom.

In Fig. 2 the pressure is exerted in two directions; one pressure, acting horizontally, tends to overthrow or slide the wall, while the other, acting vertically, tends to hold it in place.

In Fig. 3 the pressure is also exerted in two directions; one pressure, acting horizontally, tends to overthrow or slide the wall, while the other tends to lift.

So long as the vertical depth of water remains the same, the *horizontal* pressure remains the same, no matter what inclination is given the wall. Thus, in Figs. 2 and 3, the horizontal pressure is the same as in Fig. 1, or 225,000 lb.

The total pressure of the water is distributed over the entire depth of the submerged part of the back of the wall, and is least at the top, gradually increasing toward the bottom. But so far as regards the united action of every portion of it, in tending to overthrow the wall, considered as a single mass of masonry, incapable of being bent or broken, it may all be assumed to be applied at C, which is one-third of the vertical depth from the bottom in Fig. 1, or, what is the same thing, one-third of the slope distance from the bottom in Figs. 2 and 3.

No matter how much water is in a dam or vessel, the pressure remains the same, so long as the area pressed and the vertical depth of its center of gravity below the level surface of the water remains unchanged. Thus, if the water in dam shown in Fig. 1 extended back 1 mile, it would exert no more pressure against the wall than if it extended back only 1 ft.

In any two vessels having the same base, and containing the same *depth* of water, no matter what quantity, the pressures on the bases are equal. Thus, if Figs. 4 and 5 have the same base and be filled with water to the same depth, the pressure on the bases will be equal. This fact, that the pressure on a given surface, at a given

FIG. 4.

FIG. 5.

depth, is independent of the quantity of water, is called the *hydrostatic paradox.*

As the pressure of water against any point is at right angles to the surface at that point, it follows that props or other strengthening material for the strengthening of such structures as a sloping dam, should be so placed as to offer the greatest resistance in a line at right angles to the sloping surface, and these supports should be strongest and closest together at the bottom. For the same reason, the hoops on a circular tank should be strongest and closest at the bottom.

Transmission of Pressure Through Water.—Water, in common with other liquids, possesses the important property of transmitting pressure equally in all directions. Thus, if a vessel is constructed with two cylinders, the area of one being 10 sq. in., and that of the other 100 sq. in., and the vessel is filled with water (Fig. 6), and pistons fitted to the cylinders, a pressure of 100 lb. applied at the smaller will balance 1,000 lb. at the larger. This is the principle of the hydrostatic press. Air and other gaseous fluids transmit pressure equally in all directions, like liquids, but not as rapidly.

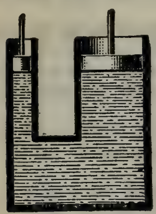


FIG. 6.

To Find the Pressure on a Plane Surface at Any Given Depth of Water.—For pounds per square inch, multiply depth in feet by .434. For pounds per square foot, multiply depth in feet by 62.5. For tons per square foot, multiply depth in feet by .0279. The pressure per square foot at different depths increases directly as the depths. The total pressure against a plane 1 ft. wide at different depths increases as the square of the depths.

PRESSURE IN POUNDS PER SQ. FT. AT DIFFERENT VERTICAL DEPTHS, AND ALSO THE TOTAL PRESSURE AGAINST A PLANE 1 FT. WIDE EXTENDING VERTICALLY FROM THE SURFACE OF THE WATER TO THE SAME DEPTHS.

Depth. Feet.	Pressure. Pounds per Sq. Ft.	Total Pressure. Pounds.	Depth. Feet.	Pressure. Pounds per Sq. Ft.	Total Pressure. Pounds.	Depth. Feet.	Pressure. Pounds per Sq. Ft.	Total Pressure. Pounds.
1	62.5	31	27	1,687	22,781	65	4,062	132,025
2	125	125	28	1,750	24,500	70	4,375	153,124
3	187	281	29	1,812	26,281	75	4,687	175,779
4	250	500	30	1,875	28,125	80	5,000	200,000
5	312	781	31	1,937	30,031	85	5,312	225,775
6	375	1,125	32	2,000	32,000	90	5,625	253,124
7	437	1,531	33	2,062	34,031	95	5,937	282,025
8	500	2,000	34	2,125	36,125	100	6,250	312,500
9	562	2,531	35	2,187	38,281	110	6,875	378,124
10	625	3,125	36	2,250	40,500	120	7,500	450,000
11	687	3,781	37	2,312	42,781	130	8,125	528,100
12	750	4,500	38	2,375	45,125	140	8,750	612,496
13	812	5,281	39	2,437	47,531	150	9,375	703,116
14	875	6,125	40	2,500	50,000	160	10,000	800,000
15	937	7,031	41	2,562	52,531	170	10,625	903,100
16	1,000	8,000	42	2,625	55,125	180	11,250	1,012,496
17	1,062	9,031	43	2,687	57,781	190	11,875	1,128,100
18	1,125	10,125	44	2,750	60,500	200	12,500	1,250,000
19	1,187	11,281	45	2,812	63,281	225	14,062	1,582,025
20	1,250	12,500	46	2,875	66,125	250	15,625	1,953,100
21	1,312	13,781	47	2,937	69,031	275	17,187	2,363,275
22	1,375	15,125	48	3,000	72,000	300	18,750	2,812,500
23	1,437	16,531	49	3,062	75,031	350	21,875	3,828,100
24	1,500	18,000	50	3,125	78,125	400	25,000	5,000,000
25	1,562	19,531	55	3,437	94,531	450	28,120	6,328,100
26	1,625	21,125	60	3,750	112,500	500	31,250	7,812,500

Pressure of Water in Pipes.—As water exerts a pressure equally in all directions, it is important that in pipe lines the pipe should be sufficiently thick to assure strength enough to resist a bursting pressure. In ordinary

practice, the thickness of cast-iron water pipes of different bores is calculated by Mr. J. T. Fanning's formula, given in his Hydraulic Engineering, which is as follows:

$$\text{Thickness in inches} = \frac{(\text{pressure in lb. per sq. in.} + 100) \times \text{bore in in.}}{.4 \times \text{ultimate tensile strength}} + .333\left(1 - \frac{\text{bore in in.}}{100}\right).$$

This formula, worked out for different heads and different sizes of bore, yields the following results:

THICKNESS OF PIPE FOR DIFFERENT HEADS AND PRESSURES.

Head in Ft.	50	100	200	300	500	1,000
Pressure in Lb. per Sq. In.	21.7	43.4	86.8	130	217	434
Bore. Inches.	Thickness of Pipe. Inches.					
2	.36	.37	.38	.39	.42	.48
3	.37	.38	.40	.42	.45	.54
4	.39	.40	.42	.45	.50	.61
6	.41	.43	.47	.50	.57	.75
8	.45	.47	.52	.57	.66	.90
10	.47	.50	.56	.62	.74	1.04
12	.49	.53	.60	.67	.82	1.18
16	.55	.60	.70	.79	.98	1.46
18	.57	.63	.74	.85	1.06	1.60
20	.61	.67	.79	.91	1.15	1.75
24	.66	.73	.87	1.02	1.30	2.03
30	.74	.83	1.01	1.19	1.55	2.46
36	.82	.93	1.15	1.36	1.80	2.88
48	.98	1.13	1.42	1.70	2.28	3.73

In the above table, the ultimate tensile strength of cast iron is taken at 18,000 lb. per sq. in. The addition of 100 lb. to the pressure is made to allow for water ram. *The valves of water pipes should be closed slowly*, and the necessity of this increases as the pipes increase in diameter. If this rule is not observed, the momentum of the running water is arrested suddenly, and a great pressure is created against the pipes in all directions, and throughout the entire length of the line above the valve, even if it be many miles, and there is danger of their bursting at any point. For this reason, stop-gates are shut by screws, because they prevent any very sudden closing; but in pipes of large diameters, even the screws must be worked very slowly to prevent bursting.

Compressibility of Liquids.—Liquids are not entirely incompressible, but they are so nearly so, that for most purposes they may be considered as incompressible. The bulk of water is diminished about $\frac{1}{1000}$ by a pressure of 324 lb. per sq. in., or 22 atmospheres; varying slightly with its temperature. It is perfectly elastic, regaining its original bulk when the pressure is removed.

Construction of Dams in Mines.—Dams may be constructed in mines, either to isolate a portion of the workings so that they can be flooded to extinguish fires, or, in cases where an extremely wet formation has been penetrated, it is sometimes expedient to construct a dam so as to prevent the water from flowing into the workings. Mine dams should be of sufficient strength to resist any column of water that will be likely to come against them. The dam should be arched toward the direction from which the pressure comes, and should be given a good firm bearing in both walls and in the floor and roof. Fig. 7 illustrates a brick dam that was constructed in Kehley's Run Colliery, at Shenandoah, Pa., to isolate a portion of the seam so that it might

be flooded to extinguish a mine fire. This is one of the largest mine dams that has ever been constructed. It is composed of three brick arches, each having a thickness of 5 ft., that are placed one against the other so that they act as one solid structure. The gangway at this point is about 20 ft. wide, and the distance to the next upper level is about 119 ft. It was intended that this should be the maximum head of water that the dams would ever have to resist, though they were made sufficiently strong to resist a head of water reaching to the surface. The separate walls were constructed one at a time, and the cement allowed to set before the next wall was placed. The back wall was carried to a greater depth and height than the others, so as to make sure of the fact that all slips or partings had been closed. The total pressure upon the dam when the water was in the mine was about 70,000 lb. per sq. ft.

Dams constructed to permit the flooding of a mine usually require no passages through them, but where dams are constructed to confine the water to certain parts of the workings, and so reduce pumping charges, it may be necessary to provide both manways and drain pipes through the

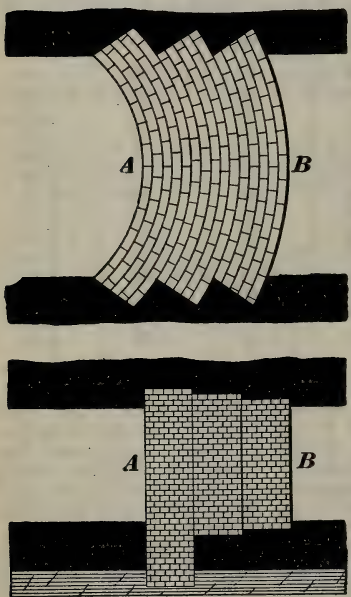


FIG. 7.

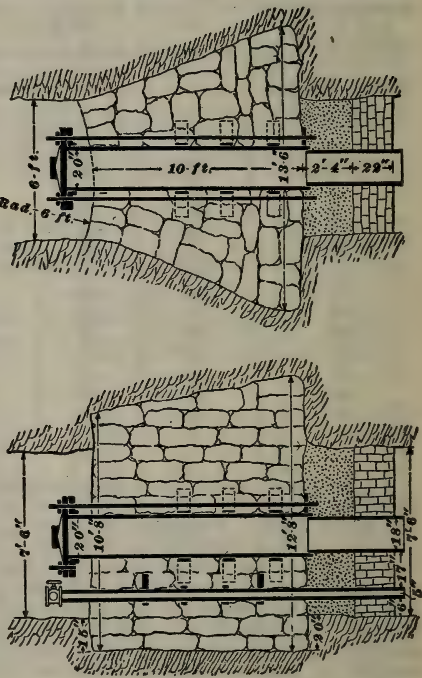


FIG. 8.

dams. Fig. 8 illustrates a plan and cross-section of a dam in the Curry Mine, at Norway, Mich. ("Mines and Minerals," Vol. 18, page 177; Trans. A. I. M. E., XXVII, 402), constructed to keep the water that came from some exploring drifts out of the mine workings. As originally constructed, it consisted of a sandstone dam 10 ft. thick and arched on the back face with a radius of 6 ft. A piece of 20″ pipe provided a manway through the masonry and was held in place by three sets of clamps and bolts passing through the stonework. A 5″ drain pipe was also carried through the dam and secured by clamps. When the pressure came upon the dam it was found to leak, so the water was drained off and a 22″ brick wall built 2 ft. 4 in. back of the dam, the space between being filled with concrete, and the manway and drain pipe extended through the brick wall. Before closing the drain pipe, horse manure was fastened against the face of the brick wall by means of a plank partition. After this the manway and drain pipe were closed, and when the pressure came on, the dam was found to leak a small

amount, but this soon practically ceased, showing that the manure had closed the leaks. A gauge in the head of the manway on this dam showed a pressure of 211 lb., which corresponded to a static head of 640 ft. of water. The total pressure against the dam was something over 800 tons, which it successfully resisted.

HYDRAULICS.

Hydraulics treats of liquids in motion, and in this, as in hydrostatics, water is taken as the type. In theory its principles are the same as those of falling bodies, but in practice they are so modified by various causes that they cannot be relied on except as verified by experiment. The discrepancy arises from changes of temperature that vary the fluidity of the liquid, from friction, the shape of the orifice, etc. As we shall deal with water only, the first cause may be thrown aside as of little account.

In theory *the velocity of a jet is the same as that of a body falling from the surface of the water.*

To Find the Theoretical Velocity of a Jet of Water.—Let v = the velocity, g = the acceleration of gravity (32.16 ft.), and d = the distance of the orifice below the surface of the water.

Then, $v = \sqrt{2gd}$, or v = the square root of twice the product of $g \times d$.

EXAMPLE.—The depth of water above the orifice is 64 ft.; what is the velocity?

Substituting 64 for d, and 32.16 for g, we have, $v = \sqrt{2 \times 32.16 \times 64}$, or 64.16.

To Find the Theoretical Quantity of Water Discharged in a Given Time.—Multiply the area of the orifice by the velocity of the water, and that product by the number of seconds.

EXAMPLE.—What quantity of water will be discharged in 5 seconds from an orifice having an area of 2 sq. ft., at a depth of 16 ft.?

$\sqrt{2 \times 32.16 \times 16} \times 2 = 64.16$ cu. ft,, or the amount discharged in 1 second, and in 5 seconds the amount will be $5 \times 64.16 = 320.8$ cu. ft.

The above rules are only theoretical, and are only useful as foundations on which to build practical formulas.

Flow of Water Through Orifices.—The standard orifice, or an orifice so arranged that the water in flowing from it touches only a line, as would be the case in flowing through a hole in a very thin plate, is used for the measurement of water. The contraction of the jet, which always occurs when water issues from a standard orifice, is due to the circumstance that the particles of water as they approach the orifice move in converging directions, and that these directions continue to converge for a short distance beyond the plane of the orifice. This contraction causes only the inner corner of the orifice to be touched by the escaping water, and takes place in orifices of any shape, its cross-section being similar to the orifice until the place of greatest contraction is passed. Owing to this contraction, the actual discharge from an orifice is always less than the theoretical discharge.

The Coefficient of Contraction.—The coefficient of contraction is the number by which the area of the orifice is to be multiplied in order to find the area of the least cross-section of the jet. In this way by experiment this coefficient has been found to be about .62 (Merriman's "Hydraulics"); or, in other words, the minimum cross-section of the jet is 62% of the cross-section of the orifice.

The Coefficient of Velocity.—The coefficient of velocity is the number by which the theoretical velocity of flow from the orifice is to be multiplied in order to find the actual velocity at the least cross-section of the jet. This may be taken for practical work as .98; or, in other words, the actual flow at the contracted section is 98% of the theoretical velocity.

The Coefficient of Discharge.—The coefficient of discharge is the number by which the theoretical discharge is to be multiplied in order to obtain the actual discharge. This has been found by thousands of experiments to be equal to the product of the coefficients of contraction and velocity, and for practical work it may be taken as .61; or, the actual discharge from standard orifices is 61% of the theoretic discharge.

NOTE.—While the coefficients for standard orifices with sharp edges have been determined fairly close, those for the more complicated cases of weirs, and especially for the flow of water through long pipes, are simply the nearest approximation to the truth that it has been possible to obtain. In all cases, the coefficient should be one that has been determined under conditions similar to those in the problem in hand. For instance, it is not practicable to use the coefficient for small pipes in solving problems relating to large ones, or for short pipes in solving problems relating to long ones.

Suppression of the Contraction.—When a vertical orifice has its lower edge at the bottom of a reservoir, the particles of water flowing through its lower portion move in lines nearly perpendicular to the plane of the orifice, and the contraction of the jet does not form on the lower side. The same thing occurs in a lesser degree when the lower edge of the orifice is within a distance of three times its least diameter from the bottom. The suppression of contraction will occur on the side if it is placed within a distance of three times its least diameter from the side of a reservoir, the suppression of contraction being the greater the nearer the orifice is to the side. By rounding the edge of the orifice sufficiently, the contraction can be completely suppressed, and the discharge can be increased. As stated before, the value of the coefficient of contraction for a standard square-edged orifice is .62, but with a rounded orifice it may have any value between .62 and 1.00, depending on the degree of rounding. The coefficient of discharge for square-edged orifices has a mean value of .61; this is increased with rounded edges and may have any value between .61 and 1.00, although it is not probable that values greater than .95 can be obtained except by the most careful adjustment of the rounded edges to the exact curve of a completely contracted jet. A rounded interior orifice is therefore always a source of error when the object of the orifice is the measurement of the discharge.

GAUGING WATER.

Water is sold by two methods; i. e., the flowing unit and the capacity unit. The flowing unit is a cubic foot per second. In the western part of North America the *miners' inch* has come into use quite largely, while in Australia and New Zealand the cubic foot per second is the common measure, 1 cu. ft. per second being 1 "head," and 10 heads of water would be 10 cu. ft. per second, regardless of the actual hydrostatic head under which the water was delivered. Water is sometimes sold for irrigation by the capacity unit, that is, so much land covered to a certain depth, as, for instance, the "acre-foot," which means that 1 acre has been covered to a depth of 1 foot, or that an amount of 43,560 cu. ft. of water has been furnished.

Miners' Inch.—The miners' inch may be roughly defined as the quantity of water that will flow in 1 minute through a vertical standard orifice having a section of 1 sq. in. and a head of 6½ in. above the center of the orifice. This quantity equals 1.53 cu. ft., and the mean quantity may be taken at, approximately, 1.5 cu. ft. per minute. The laws or customs defining the miners' inch in different districts vary so that the amount of water actually delivered varies from 1.2 to 1.76 cu. ft. per minute, the principal reasons for these variations being the method adopted for measuring the water where large quantities are used; as, for instance, at Smartsville, in California, an opening 4 in. deep, 250 in. long, with a head of 7 in. above the top edge, is said to furnish 1,000 miners' inches, while it would actually furnish considerably over 1,000. In other places, the size of the opening for measuring the amounts is restricted, and may actually furnish less than the rated amount. In Montana the common method of measurement was formerly through a vertical rectangle 1 in. high, with a head on the center of the orifice of 4 in. The number of miners' inches discharged was considered to be the same as the number of linear inches in the length of the orifice; thus, under the given head, an orifice 1 in. deep and 60 in. long could discharge 60 miners' inches.

The State Legislature of Montana has now passed a law defining the miners' inch as the number of gallons of water discharged in a given time, regardless of the character of the openings or methods of measurement. The statement is as follows: "Where water rights, expressed in miners' inches, have been granted, 100 miners' inches shall be considered equivalent to a flow of 2½ cu. ft. (18.7 gal.) per second, and this proportion shall be observed in determining the equivalent flow represented by any number of miners' inches."

If this amount is reduced to cubic feet per minute, it will be found to be equal to a flow of 1.5 cu. ft. per minute, which is the value given above for the miners' inch.

Duty or Work Performed by a Miners' Inch of Water.—Few tests have been made in regard to the duty of a miners' inch of water, but the North Bloomfield mine and the La Grange mine, in California, have carried on a series of experiments extending over several years. At the La Grange mine the observations were carried on simultaneously upon several different claims, hence parallel dates appear. The accompanying tables give the results of these experiments. In general it is governed by the size, capacity, character of pavement, and grade of sluices, together with the supply of water. A heavy grade will compensate for a limited supply. With an abundant supply of water and material, the capacity of the sluices will depend on: *First*, the character of the material washed; *second*, the size and minimum grade of the sluices; *third*, the character of the riffles used.

DUTY OF MINERS' INCH.
(*Risdon Iron Works, Evans's Elevator Catalogue.*)

NORTH BLOOMFIELD MINE.

Years.	Cubic Yards of Gravel Washed.	Miners' 24-Hour Inches.	Grades.	Cubic Yards Washed per Miners' Inch.	Cubic Feet of Water Used per Cubic Feet of Gravel Moved.	Height of Bank.	Remarks.
1870-74	3,250,000	710,987	6½ in. to 12 ft.	4.60	18	100 ft.	Sluices 6 ft. wide, 32 in. deep. Riffles principally blocks (wood), but rock riffles in tail sluices. The larger portion of the material moved was top gravel.
1875	1,858,000	386,972	6½ in. to 12 ft.	4.80	17	100 ft.	
1876	2,919,700	700,000	6½ in. to 12 ft.	4.17	20	200 ft.	
1877	2,993,930	595,000	6½ in. to 12 ft.	3.86	21	265 ft.	
Totals	11,021,630	2,392,959		4.60	18		

LA GRANGE MINE.

Years.	Cubic Yards of Gravel Washed.	Miners' 24-Hour Inches.	Grades.	Cubic Yards Washed per Miners' Inch.	Cubic Feet of Water Used per Cubic Feet of Gravel Moved.	Height of Bank.	Remarks.
1874-76	676,968	624.745	4 in. to 16 ft.	1.08	74.0	10 to 48 ft.	Sluices 4 ft. wide and 30 in. deep, paved with blocks.
1875-76	683,244	375,155	4 in. to 16 ft.	1.82	43.9	6 ft.	
1874-76	284,932	207,010	4 in. to 16 ft.	1.37	58.0	50 to 80 ft.	
1875-78	459,570	302,960	4 in. to 16 ft.	1.52	52.0	40 to 50 ft.	
1880-81	329,120	203,325	4 in. to 16 ft.	1.57	50.0	10 to 80 ft.	
Totals	2,433,834	1,713,195		1.42	56.0		

The **right-angled V notch** is frequently used for gauging the flow of comparatively small streams. The notch is usually fitted into a box provided with baffle boards, Fig. 9, or where this is not practicable the water should be so impounded above the notch as to remove all possibility of surface currents producing a perceptible velocity of approach. The distance a of the surface of the water below the top of the box is taken at a point some distance back from the notch (at least 18 to 20 in.), where the surface of the water is unaffected by the flow through the notch. The distance a, subtracted from the total depth of the notch H, gives the head h of the water passing over the notch. The discharge in cubic feet per second may be found by the formula

$$Q = .306\sqrt{h^5} = .306\,h^2\sqrt{h},$$

in which Q equals the quantity in cubic feet per minute and h equals the

head in inches. The accompanying table gives the discharge in cubic feet per minute through a right-angled **V** notch, as shown in Fig. 9, for heads varying from 1.05 in. to 12 in.

TABLE I.

DISCHARGE OF WATER THROUGH A RIGHT-ANGLED **V** NOTCH.

h Head. Inches.	Q Quantity per Min. Cu. Ft.	h Head. Inches.	Q Quantity per Min. Cu. Ft.	h Head. Inches.	Q Quantity per Min. Cu. Ft.	h Head. Inches.	Q Quantity per Min. Cu. Ft.	h Head. Inches.	Q Quantity per Min. Cu. Ft.
1.05	.3457	3.25	5.827	5.45	21.22	7.65	49.53	9.85	93.18
1.10	.3884	3.30	6.054	5.50	21.71	7.70	50.34	9.90	94.37
1.15	.4340	3.35	6.285	5.55	22.20	7.75	51.16	9.95	95.56
1.20	.4827	3.40	6.523	5.60	22.70	7.80	51.99	10.00	96.77
1.25	.5345	3.45	6.765	5.65	23.22	7.85	52.83	10.05	97.98
1.30	.5896	3.50	7.012	5.70	23.74	7.90	53.67	10.10	99.20
1.35	.6480	3.55	7.266	5.75	24.26	7.95	54.53	10.15	100.43
1.40	.7096	3.60	7.524	5.80	24.79	8.00	55.39	10.20	101.67
1.45	.7747	3.65	7.788	5.85	25.33	8.05	56.26	10.25	102.92
1.50	.8432	3.70	8.058	5.90	25.87	8.10	57.14	10.30	104.18
1.55	.9153	3.75	8.332	5.95	26.42	8.15	58.03	10.35	105.45
1.60	.9909	3.80	8.613	6.00	26.98	8.20	58.92	10.40	106.73
1.65	1.0700	3.85	8.899	6.05	27.55	8.25	59.82	10.45	108.02
1.70	1.1530	3.90	9.191	6.10	28.12	8.30	60.73	10.50	109.31
1.75	1.2400	3.95	9.489	6.15	28.70	8.35	61.65	10.55	110.62
1.80	1.3300	4.00	9.792	6.20	29.28	8.40	62.58	10.60	111.94
1.85	1.4240	4.05	10.100	6.25	29.88	8.45	63.51	10.65	113.26
1.90	1.5220	4.10	10.410	6.30	30.48	8.50	64.45	10.70	114.60
1.95	1.6250	4.15	10.730	6.35	31.09	8.55	65.41	10.75	115.94
2.00	1.7310	4.20	11.060	6.40	31.71	8.60	66.37	10.80	117.29
2.05	1.8410	4.25	11.390	6.45	32.33	8.65	67.34	10.85	118.65
2.10	1.9550	4.30	11.730	6.50	32.96	8.70	68.32	10.90	120.02
2.15	2.0740	4.35	12.070	6.55	33.60	8.75	69.30	10.95	121.41
2.20	2.1960	4.40	12.420	6.60	34.24	8.80	70.30	11.00	122.81
2.25	2.3230	4.45	12.780	6.65	34.89	8.85	71.30	11.05	124.21
2.30	2.4550	4.50	13.140	6.70	35.56	8.90	72.31	11.10	125.61
2.35	2.5900	4.55	13.510	6.75	36.23	8.95	73.33	11.15	127.03
2.40	2.7300	4.60	13.890	6.80	36.89	9.00	74.36	11.20	128.45
2.45	2.8750	4.65	14.270	6.85	37.58	9.05	75.40	11.25	129.90
2.50	3.0240	4.70	14.650	6.90	38.27	9.10	76.44	11.30	131.35
2.55	3.1770	4.75	15.040	6.95	38.96	9.15	77.49	11.35	132.81
2.60	3.3350	4.80	15.440	7.00	39.67	9.20	78.55	11.40	134.27
2.65	3.4980	4.85	15.850	7.05	40.38	9.25	79.63	11.45	135.75
2.70	3.6660	4.90	16.260	7.10	41.10	9.30	80.71	11.50	137.23
2.75	3.8380	4.95	16.680	7.15	41.83	9.35	81.80	11.55	138.73
2.80	4.0140	5.00	17.110	7.20	42.56	9.40	82.90	11.60	140.23
2.85	4.1960	5.05	17.540	7.25	43.30	9.45	84.01	11.65	141.75
2.90	4.3820	5.10	17.970	7.30	44.06	9.50	85.12	11.70	143.28
2.95	4.5740	5.15	18.420	7.35	44.82	9.55	86.24	11.75	144.82
3.00	4.7700	5.20	18.870	7.40	45.58	9.60	87.37	11.80	146.36
3.05	4.9710	5.25	19.320	7.45	46.36	9.65	88.52	11.85	147.91
3.10	5.1780	5.30	19.790	7.50	47.14	9.70	89.67	11.90	149.48
3.15	5.3880	5.35	20.260	7.55	47.92	9.75	90.83	11.95	151.05
3.20	5.6050	5.40	20.730	7.60	48.72	9.80	92.00	12.00	152.64

1 cu. ft. contains 7.48 U. S. gallons; 1 U. S. gallon weighs 8.34 lb.

Gauging by Weirs.—A weir is an obstruction placed across a stream for the purpose of diverging the water so as to make it flow through a desired channel, which may be a notch or opening in the weir itself. The term usually applies to rectangular notches in which the water touches only the bottom and ends, the opening being a notch without any upper edge. Weirs are of two general classes: *weirs with end contractions*, Fig. 10 (a), and *weirs without*

end contractions, Fig. 10 (b). The crest and edges of the weir with end contractions should be sharp, as shown at a, Fig. 10 (c) and (d). The head of water H producing the flow over the weir should be measured at a sufficient distance from the crest to avoid the effects of the curve of the surface as it flows over the crest. The water above the weir should be motionless, or if it has any perceptible current toward the weir, this should be determined and taken into account in the formula. Fig. 11 illustrates a weir constructed across a small stream for measuring its flow. The head is measured from the stake E some distance back of the weir, the top of the stake being level with the crest of the weir B. The discharge over the weir may be calculated from the following formula:

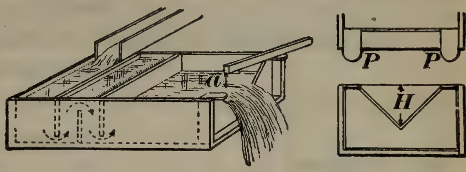


FIG. 9.

Let l = length of weir in feet;
H = head in feet;
v = velocity with which the water approaches the weir in feet;
h = a head equivalent to the velocity with which the water approaches the weir;
c = coefficient of discharge;
Q = theoretic discharge in cubic feet per second;
Q' = actual discharge in cubic feet per second.

For weirs with end contractions and a velocity of approach, the actual discharge is

$$Q = 5.347\,c\,l\sqrt{(H + 1.4\,h)^3}.$$

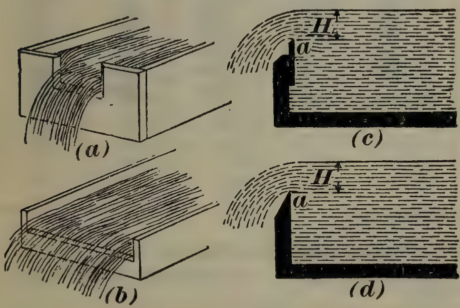


FIG. 10.

Where the water has no velocity of approach,

$$Q = 5.347\,c\,l\sqrt{H^3}.$$

For weirs without end contractions, but with a velocity of approach, the actual discharge is

$$Q = 5.347\,c\,l\sqrt{(H + \tfrac{4}{3}\,h)^3}.$$

Where the water has no velocity of approach,

$$Q = 5.347\,c\,l\sqrt{H^3}.$$

The velocity with which the water approaches the weir may be found by determining the approximate discharge from the stream without any allowance for velocity of approach, and then dividing this discharge in cubic feet per second by the area of the stream in square feet where it approaches the weir, which will give the velocity of approach in feet per second. Having obtained the value of v, the equivalent head h may be found by the formula

$$h = 0.01555\,v^2.$$

Since v is small in a properly constructed weir, it is usually neglected unless great accuracy is required.

FIG. 11.

The values of coefficients of discharge, as determined from experiments for weirs with end contractions, are given in Table II, and for weirs without end contractions in Table III. The values of the coefficients in Tables II and III are given in feet and tenths. Frequently

in measuring water where only a close approximation is required, it is desired to take all of the measurement in feet and inches. See Table IV.

TABLE II.

VALUES OF THE COEFFICIENT OF DISCHARGE FOR WEIRS WITH END CONTRACTIONS.

Effective Head. Feet.	Length of Weir. Feet.						
	.66	1	2	3	5	10	19
.10	.632	.639	.646	.652	.653	.655	.656
.15	.619	.625	.634	.638	.640	.641	.642
.20	.611	.618	.626	.630	.631	.633	.634
.25	.605	.612	.621	.624	.626	.628	.629
.30	.601	.608	.616	.619	.621	.624	.625
.40	.595	.601	.609	.613	.615	.618	.620
.50	.590	.596	.605	.608	.611	.615	.617
.60	.587	.593	.601	.605	.608	.613	.615
.70		.590	.598	.603	.606	.612	.614
.80			.595	.600	.604	.611	.613
.90			.592	.598	.603	.609	.612
1.00			.590	.595	.601	.608	.611
1.20			.585	.591	.597	.605	.610
1.40			.580	.587	.594	.602	.609
1.60				.582	.591	.600	.607

TABLE III.

VALUES OF THE COEFFICIENT OF DISCHARGE FOR WEIRS WITHOUT END CONTRACTIONS.

Effective Head. Feet.	Length of Weir. Feet.						
	19	10	7	5	4	3	2
.10	.657	.658	.658	.659			
.15	.643	.644	.645	.645	.647	.649	.652
.20	.635	.637	.637	.638	.641	.642	.645
.25	.630	.632	.633	.634	.636	.638	.641
.30	.626	.628	.629	.631	.633	.636	.639
.40	.621	.623	.625	.628	.630	.633	.636
.50	.619	.621	.624	.627	.630	.633	.637
.60	.618	.620	.623	.627	.630	.634	.638
.70	.618	.620	.624	.628	.631	.635	.640
.80	.618	.621	.625	.629	.633	.637	.643
.90	.619	.622	.627	.631	.635	.639	.645
1.00	.619	.624	.628	.633	.637	.641	.648
1.20	.620	.626	.632	.636	.641	.646	
1.40	.622	.629	.634	.640	.644		
1.60	.623	.631	.637	.642	.647		

TABLE IV.

Weir Table Giving Cubic Feet Discharged per Minute for Each Inch in Length of Weir for Depths From $\frac{1}{8}$ In. to 25 In.

This table should not be used unless the length of the crest is at least 3 or 4 times the depth of water passing over the weir, for if this is not the case, there will be serious errors caused by end contractions.

Inches.	0	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$
0		.01	.05	.09	.14	.20	.26	.33
1	.40	.47	.55	.65	.74	.83	.93	1.03
2	1.14	1.24	1.36	1.47	1.59	1.71	1.83	1.96
3	2.09	2.23	2.36	2.50	2.63	2.78	2.92	3.07
4	3.22	3.37	3.52	3.68	3.83	3.99	4.16	4.32
5	4.50	4.67	4.84	5.01	5.18	5.36	5.54	5.72
6	5.90	6.09	6.28	6.47	6.65	6.85	7.05	7.25
7	7.44	7.64	7.84	8.05	8.25	8.45	8.66	8.86
8	9.10	9.31	9.52	9.74	9.96	10.18	10.40	10.62
9	10.86	11.08	11.31	11.54	11.77	12.00	12.23	12.47
10	12.71	13.95	13.19	13.43	13.67	13.93	14.16	14.42
11	14.67	14.92	15.18	15.43	15.67	15.96	16.20	16.46
12	16.73	16.99	17.26	17.52	17.78	18.05	18.32	18.58
13	18.87	19.14	19.42	19.69	19.97	20.24	20.52	20.80
14	21.09	21.37	21.65	21.94	22.22	22.51	22.79	23.08
15	23.38	23.67	23.97	24.26	24.56	24.86	25.16	25.46
16	25.76	26.06	26.36	26.66	26.97	27.27	27.58	27.89
17	28.20	28.51	28.82	29.14	29.45	29.76	30.08	30.39
18	30.70	31.02	31.34	31.66	31.98	32.31	32.63	32.96
19	33.29	33.61	33.94	34.27	34.60	34.94	35.27	35.60
20	35.94	36.27	36.60	36.94	37.28	37.62	37.96	38.31
21	38.65	39.00	39.34	39.69	40.04	40.39	40.73	41.09
22	41.43	41.78	42.13	42.49	42.84	43.20	43.56	43.92
23	44.28	44.64	45.00	45.38	45.71	46.08	46.43	46.81
24	47.18	47.55	47.91	48.28	48.65	49.02	49.39	49.76

CONVERSION FACTORS.

Cubic Feet Into Gallons:

$$1 \text{ cu. ft.} = 1{,}728 \text{ cu. in.} = \frac{1{,}728}{231} \text{ gal.} = 7.4805194 \text{ gal.}$$

Gallons Into Cubic Feet:

$$1 \text{ United States liquid gal.} = 231 \text{ cu. in.} = \frac{231}{1{,}728} \text{ cu. ft.} = .133680555 \text{ cu. ft.}$$

Feet per Second Into Miles per Hour:

$$1 \text{ ft. per sec.} = 3{,}600 \text{ ft. per hr.} = \frac{3{,}600}{5{,}280}, \text{ or } \frac{15}{22} \text{ miles per hour.}$$

Miles per Hour Into Feet per Second:

$$1 \text{ mi. per hr.} = 5{,}280 \text{ ft. per hr.} = \frac{5{,}280}{3{,}600}, \text{ or } \frac{22}{15} \text{ ft. per sec.}$$

Second-Feet per Day Into Gallons:

1 second-foot, or 7.4805194 gal. per sec. for 1 day, or 86,400 sec. = 646,316.87616 gal.

Millions of Gallons Into Second-Feet per Day:

$$1{,}000{,}000 \text{ gal. per 24 hr.} = \frac{231{,}000{,}000}{1{,}728 \times 86{,}400} \text{ cu. ft. per sec., or } 1.5472286 \text{ second-feet.}$$

Second-Feet per Day Into Acre-Feet:

$$1 \text{ second-foot flow for 1 day} = 86{,}400 \text{ cu. ft.} = \frac{86{,}400}{43{,}560}, \text{ or } 1.983471 \text{ acre-feet.}$$

Acre-Feet Into Second-Feet Flow for 24 Hours:

One acre-foot each 24 hr. = 43,560 cu. ft. each 86,400 sec.

$$= \frac{43{,}560}{86{,}400}, \text{ or } \frac{121}{240} \text{ second-foot flow for 24 hr.}$$

Acre-Feet Into Gallons:

$$1 \text{ acre-foot} = 43{,}560 \text{ cu. ft.} = \frac{43{,}560 \times 1{,}728}{231}, \text{ or } \frac{75{,}271{,}680}{231}, \text{ or } 325{,}851.428 \text{ gal.}$$

Millions of Gallons Into Acre-Feet:

1,000,000 United States liquid gal., or 231,000,000 cu. in. = 133,680.555 cu. ft.,

$$\text{or } \frac{133{,}680}{43{,}560} = 3.0688832 \text{ acre-feet.}$$

Second-Feet Into Minute Gallons:

FACTORS: 1 cu. ft. contains 1,728 cu. in.; 1 gal. has a capacity of 231 cu. in.; 1 second-foot equals [(1,728 ÷ 231) × 60] gal. per min., or 448.831164 minute-gallons.

Minute-Gallons Into Second-Feet:

FACTORS: 1 gal. contains 231 cu. in.; 1 cu. ft. contains 1,728 cu. in.; 1 gal. per min. equals [(231 ÷ 1,728) ÷ 60] second-feet, or .0022280092 second-foot.

FLOW OF WATER IN OPEN CHANNELS.

Ditches.—In the case of hydraulic mining and irrigation, water is usually conveyed through ditches. The ditch line should be carefully surveyed and all brush and trees removed, and the underbrush cut away and burned, before beginning to excavate the ditch.

The following letters will be used in the formulas for determining the various factors relating to ditches:

h = difference in level between ends of canal or ditch, or between two points under consideration;
l = horizontal length of portion of canal or ditch under consideration;
s = slope = ratio $\frac{h}{l}$ = sin of slope;
a = area of water cross-section in square feet;
p = wet perimeter = portion of outline of cross-section of stream in contact with channel, in feet;
r = hydraulic radius, or hydraulic mean depth = ratio $\frac{a}{p}$;
c' = coefficient, depending on nature of surface of the ditch;
c = coefficient depending on nature of surface of ditch, as determined by Kutter's formula;
v = mean velocity of flow in feet per second;
v' = surface velocity of a stream;
v_b = bottom velocity of a stream;
x = bottom or one side of a section, the form of which is half a regular hexagon, in feet;
Q = quantity of water flowing, in cubic feet per second;
n = coefficient of roughness in Kutter's formula.

The form of ditch and its grade will depend largely on the amount of water to be conveyed and the character of the soil in the section under consideration. As a general rule, the average flow of water in a ditch should not be less than 2 ft. per second, and under most circumstances should not exceed 4 ft., though in rare cases where the formation is suitable, mean velocities of 5 ft. per second are employed. Sand will deposit from a current flowing at the rate of 1¼ ft. per second, and if the current does not have a velocity of at least 2 ft. per second, vegetation is liable to block the ditch line.

Safe Bottom Velocity.—The bottom velocity of a stream may be obtained from the average velocity by the following formula: $v_b = v - 10.87\sqrt{rs}$.

The following table gives values of safe bottom and mean velocities, corresponding with certain materials, as given by Ganguillet and Kutter:

Material of Channel.	Safe Bottom Velocity v_b. Feet per Second.	Mean Velocity v. Feet per Second.
Soft brown earth	.249	.328
Soft loam	.499	.656
Sand	1.000	1.312
Gravel	1.998	2.625
Pebbles	2.999	3.938
Broken stone, flint	4.003	5.579
Conglomerate, soft slate	4.988	6.564
Stratified rock	6.006	8.204
Hard rock	10.009	13.127

Resistance of Soils to Erosion by Water.—W. A. Burr, "Engineering News," February 8, 1894, gives a diagram showing the resistance of various soils to erosion by water. The following values have been selected from Mr. Burr's work for different kinds of soil:

Pure sand resists erosion by flow of	1.10 ft. per sec.
Sandy soil, 15% clay	1.20 ft. per sec.
Sandy loam, 40% clay	1.80 ft. per sec.
Loamy soil, 65% clay	3.00 ft. per sec.
Clay loam, 85% clay	4.80 ft. per sec.
Agricultural clay, 95% clay	6.20 ft. per sec.
Clay	7.35 ft. per sec.

Carrying Capacity of Ditches.—Ditches should never be run full, but should be constructed large enough so that they will carry the desired amount of water when from $\frac{3}{4}$ to $\frac{7}{8}$ full. For any given cross-section, the greatest flow will be attained when the hydraulic radius or hydraulic mean depth is equal to one-half of the actual depth of the channel. The cross-section of a ditch or conduit that has the greatest possible carrying capacity is a half circle, and the nearest practical approach to this is a half hexagon. Knowing the cross-section of a ditch, its dimensions may be found by the formula:

$$x = \sqrt{\frac{2a}{2.598}}.$$

As the obtuse angle between the side and bottom of the ditch is 120°, the form can be easily laid off. The carrying capacity of ditches generally increases after they have been in use some time, as the ditch becomes lined with a fine scum that closes the pores in the soil and prevents leakage. This may increase the amount to as much as 10%.

Grade.—The grade of the ditch must be sufficient to create the desired velocity of flow, and depends largely on the character of the material composing the surfaces of the ditch. If the surface is smooth, as, for instance, where the ditch is cut through clay or is lined with masonry, the grade can be considerably less than where the surface is rough, or when cut through coarse gravel or when lined with rough stone. In mountainous countries, where the ground is hard, deep narrow ditches with steep grades are generally preferred to larger channels with gentle slopes, as the cost of excavation is considerably less; but steep grades and narrow ditches are suitable only when the banks can resist the rapid flow. In California, grades of from 16 to 20 ft. per mile are used, and 10 ft. per mile is quite common. Water channels of a uniform cross-section should have a uniform grade, otherwise, the flow will be checked in places, which will result in deposits of sand or silt in some portions of the ditch, which are liable to cause the banks to be overflowed and the ditch to be ultimately destroyed. In designing any given ditch, the grade is generally assumed to correspond to the formation of the country and the velocity figured from the grade. In case v is found to be so great that it would cut the banks, it will be necessary either to reduce the grade or to change the form of the ditch so as to reduce the velocity.

Ditch banks, when possible, should be composed of solid material, but frequently it is necessary to use excavated material. Where this is the case, care must be taken to see that the material is so placed as to avoid settling

and cracking as much as possible. All stumps, roots, etc. should be separated from the material to be used for embankments. If artificial banks are necessary, it is best to build them of masonry, provided the expense is not too great; or, the water may be carried across depressions in pipes or flumes. When the character of the material through which the ditch is constructed is not sufficiently firm to resist the desired current velocity, it becomes necessary to line the ditch. In some locations the ditches are simply smoothed on the inside and lined with from $\frac{3}{4}$ in. to 1 in. of cement mortar, made up of Portland cement and sharp sand. In other cases they are lined with dry stonework laid up in order and carefully bonded together. Sometimes the stonework is pointed with cement or mortar on the inside, so as to present a more uniform surface to the flow. In other cases, the sides are simply revetted with stone.

Influence of Depth on Ditch.—The depth of the flow in a ditch has considerable influence on the scouring or eroding of the bottom and the banks, owing to the fact that a much greater average velocity can be attained in a deep stream than in a shallow stream, without causing an excessive velocity of the water in contact with the wet perimeter. For this reason, in cases where banks will stand it, it is best to use narrow deep ditches rather than wide flat ditches, though each location has to be treated in accordance with its own special conditions, and no general rule can be laid down.

Measuring the Flow of Water in Channels.—The laws for the resistance to the flow may be expressed by the relation (see page 142 for significance of letters):

$$h a = c' l p v^2; \text{ or, } v = \sqrt{\frac{h}{c' l} \times \frac{a}{p}} = \sqrt{\frac{l}{c'} \times s \times r}.$$

If $c = \sqrt{\frac{l}{c'}}$, the formula becomes $v = c\sqrt{r s}$.

The coefficient c is usually found by means of Kutter's formula, one form of which is as follows:

$$c = \frac{23 + \frac{1}{n} + \frac{.00155}{s}}{.5521 + \left(23 + \frac{.00155}{s}\right)\frac{n}{\sqrt{r}}}.$$

The values for n, the coefficient of roughness, under various conditions, are as follows:

Character of Channel.	Value of n.
Clean, well-planed timber	.009
Clean, smooth, glazed iron, and stoneware pipes	.010
Masonry, smoothly plastered with cement, and for very clean, smooth, cast-iron pipe	.011
Unplaned timber, ordinary cast-iron pipe, and selected pipe sewers, well laid and thoroughly flushed	.012
Rough iron pipes and ordinary sewer pipes, laid under the usual conditions	.013
Dressed masonry and well-laid brickwork	.015
Good rubble masonry and ordinary rough or fouled brickwork	.017
Coarse rubble masonry and firm, compact gravel	.020
Well-made earth canals in good alinement	.0225
Rivers and canals in moderately good order and perfectly free from stones and weeds	.025
Rivers and canals in rather bad condition and somewhat obstructed by stones and weeds	.030
Rivers and canals in bad condition, overgrown with vegetation and strewn with stones and other detritus, according to condition	.035 to .050

As it is quite difficult to obtain the value of c by Kutter's formula, the following three approximate formulas for v are given:

For canals with earthen banks, $v = \sqrt{\frac{100,000\, r^2 s}{9 r + 35}}$.

If the ditch is lined with dry stonework, $v = \sqrt{\frac{100,000\, r^2 s}{8 r + 15}}$.

If the ditch is lined with rubble masonry, $v = \sqrt{\frac{100,000\, r^2 s}{7.3 r + 6}}$.

To find the quantity Q of water flowing through any channel in a given time, multiply the velocity by the area, or $Q = a v$.

Flow in Brooks and Rivers.—When a stream is so large that it becomes impracticable to employ a weir for measuring its flow, fairly accurate results may be arrived at by determining the velocity of the current at various points in a carefully surveyed cross-section of the stream, thus determining both v and a. The greatest velocity of current occurs at a point some distance below the surface, in the deepest part of the channel. When determining the current velocities in the different portions of a stream, it is frequently advantageous to divide the stream into divisions. This may be accomplished by stretching a wire across and tying strings or rags about the wire at various points. The mean velocity of the current between these points can be determined by current meters, or by floats. The points for observation should be chosen where the channel is comparatively straight and the current uniform. Surface floats may be used, in which case the mean velocity of the point where the float is used may be found as follows: If v' equals the observed velocity, then the mean velocity will be $v = .9\, v'$.

By taking observations of the velocity of the current in each section of a stream, the amount of water flowing may be determined for each separate section. The total amount of water flowing in the stream will be the sum of the amounts in each section. The average velocity of the entire stream may be found by dividing the total amount of water flowing by total area of the cross-section of the stream. The correction necessary to reduce surface velocity to mean velocity may be made as follows: Measure off $\frac{9}{10}$ of the ordinary distance, and figure the time as though for the full distance. For instance, if only 90 ft. were employed, the time would be taken and the problem figured as though it were 100 ft., on account of the fact that the mean velocity is only $\frac{9}{10}$ of the surface velocity.

FLUMES.

Flumes are used for conveying water when a ditch line would be abnormally long, or when the material to be excavated is very hard. They may be constructed of timber or of metal, but metal flumes are comparatively rare, as piping can be used instead. The line of the proposed flume should be carefully cleared of all standing timber, and the brush burned for at least 20 ft. each side of the flume line to prevent danger from fire. The life of an ordinary flume, which is supported on or constructed of timber, is always short, varying, as a rule, from 10 to 20 years, depending on whether the flume is allowed to run dry a portion of the year or is always full of water, the care with which it was originally constructed, and the attention paid to repairs.

Grade of Flumes.—Flumes are usually set on a much steeper grade than is possible in ditches, the grade frequently being as much as 25 to 30 ft. per mile, and in special cases even more. The result of this is that the carrying capacity of flumes is much greater than that of ditches of the same size.

The **form of flume** depends largely on the material of which it is constructed. Metal flumes may have a semicircular form, while wooden flumes are either rectangular or **V**-shaped. The former is used almost exclusively for conveying water, and the latter quite extensively for fluming timber or cord wood from the mountains to the shipping point in the valley.

Timber flumes should be so constructed that the water will meet with but small resistance, and the bottom and side should be enclosed in a frame of timbers so braced or secured that there is no possible chance of the sides spreading or lifting from the bottom, and thus cause leakage. As a rule, all mortised and tenoned joints should be avoided in flume construction.

Fig. 22 shows a timber flume in which no joints are cut, the bents of the flume being kept in place by stringers spiked on the side and the ties tied together by braces nailed on. Fig. 23 shows construction in which the posts are set into the sill and supported by diagonal braces. The horizontal ties of the posts are also notched to receive the upper ends of the posts. As a rule, in such a construction, these ties are only placed on every third or fourth bent, the diagonal bracing depended on to hold the other posts in place. The joints between the planking may be battened, side to side with strips of 2" thick, 4 or 5 in. wide, or the edges of the planking may be tongued and grooved, so that they are put together so as to form a tight joint.

Fig. 22.

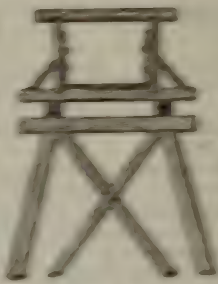


Fig. 23.

Connection With Gates. Where flumes connect with ditches or dams, the posts of several bents should be made longer, so that they may receive either siding inward to prevent the water from splashing over the sides. The flume should also be widened out or flared, both at its entry and the outlet. Where the flume passes through a bank of earth, an outer siding should be nailed on the outside of the posts, to protect the flume from rotting.

Trestles.—Where flumes are carried on trestles, the individual bents supporting the flume are usually placed on heavy stringers, which in turn are supported upon trestle bents from 12 to 16 ft. apart, the frames supporting the flume being placed about 4 ft. apart.

Curves.—Where flumes are laid around curves, the outer edge of the flume should be elevated so as to prevent splashing and to cause the flowing water to have a uniform depth across the width of the flume. It is impossible to give any definite rule as to the amount that the outer edge of the flume should be raised, but this is usually accomplished by judging the amount when the flume is first constructed, and correcting this by wedging after the water is flowing. The individual boxes of the flume may be cut into 2 or 3 portions on curves, and at times the side planks are sawed vertically through, so as to enable them to be bent to the desired curve.

Waste gates should be placed every half mile, to empty the flume for repairs, or in case of accident. They are also useful for flushing [illegible] of a flume. In snow regions, flumes are frequently protected by [illegible] over their exposed portions.

Flow of Water Through Flumes.—As smooth wooden surfaces offer considerably less resistance to the flow of water than earth or stone [illegible], the coefficients must necessarily be somewhat reduced, and the following formula is useful in giving the flow of water through flumes:

$$v = \sqrt{\frac{100{,}000\, r s}{4.5\, r + 0.35}}$$

That flumes may have their full carrying capacity, they have to be of sufficient length to get the water in motion, or, as it is technically expressed, "to put the water in train." It is largely on this account that flumes have to be made of a larger cross-section at both the entrance and the outlet. In cold countries it may be best to construct the flume narrower than it is deep, as in cold weather the ice in the narrow flume freezes across [illegible] the surface, thus protecting the water from further action of the elements and frequently prolonging the flow through the flume for several weeks, while wide shallow flumes will not freeze on the surface so quickly, but will freeze to form the bottom and sides until they are practically a solid mass of ice. Where a flume is laid on the ground along a bank, it should be laid as close to the bank as possible, so as to protect it from slides or landslides, and so that in the winter the snow will drift in under and behind, thus preventing the circulation of the air around the flume. This will protect the flume, and may prolong the flow for some time after cold weather sets in.

TUNNELS.

Tunnels are sometimes used for conveying water, in connection with flume or ditch lines. Where a tunnel is unlined, it is best to give the roof the shape of the Gothic arch, owing to the fact that this stands better and resists scaling to a greater extent than the round arch, which usually scales off until it has the form of the Gothic arch. If tunnels are to be used as water conduits, without lining, care should be taken to make the inside of the tunnel as smooth as possible. In some cases, in order to increase the carrying capacity of the tunnel, they have been lined with wooden-stave pipe, backed with concrete, the pipe requiring no metal bands, but depending on the concrete to keep it in place. When such linings are employed, it is not practicable to have them exposed to the alternate action of the water and the atmosphere, hence the tunnel should be kept continually full of water. To accomplish this, the tunnel may be dropped below the grade of the ditch or flume line, so that it is always under a slight hydrostatic pressure, and even if the water were turned off from the line, the tunnel would remain full of water, the same as an inverted siphon. Sometimes tunnels are lined with cement, being given either a circular or oval form, or they may have a flat bottom, with flat sides and an arched roof. The cement may be placed directly on the country rock composing the walls of the tunnel, or the tunnel may be lined with brick or stone, and then cemented on the inside.

Flow Through Tunnels.—The flow of water through tunnels, when they are only partially filled, is calculated by the formulas for flow in open channels, while in the case of lined tunnels that are run full, the flow is calculated by formulas for calculating the flow through pipes.

FLOW THROUGH PIPES.

Hydraulic Gradient.—If a pipe of uniform cross-section be connected with a reservoir, and water allowed to discharge through its open end, it has been found that the pressure on the pipe at any point is equal to the vertical distance from the center of the pipe at that point to an imaginary line, called the *hydraulic gradient* or *hydraulic grade line.* This is a line drawn from a point slightly below the surface of the water in the reservoir to the outlet of the pipe, as $a b$, Fig. 14. The distance from the surface of the water to the point a is equal to the head lost in overcoming the friction at the entrance to the pipe, and is rarely over 1 ft. If the pipe were laid along the line $a b$, it would carry exactly the same amount of water as when laid horizontally, as shown, but there would be practically no pressure tending to burst the pipe at any point along this line; while if it were laid along the line from the point a' (the reservoir being made deeper), it would still deliver exactly the same amount of water, but the pressure tending to burst the pipe would be greatly increased. In order that a pipe may have a maximum discharge, no point in the line must rise above the hydraulic gradient, and it makes no difference in the discharge how far below the gradient it may fall.

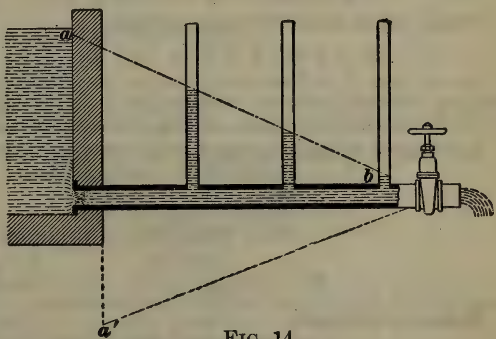


FIG. 14.

In Fig. 15, the pipe rises above the hydraulic gradient $a c$, and in this case a new hydraulic gradient $a b$ would have to be established, and the flow calculated for this head, the pipe $b c$ simply acting to carry off the water delivered to it at b. If the upper side of the pipe were open at the point b, the water would have no tendency to escape, but, on the contrary, air would probably enter, and the pipe flow only partially full from b to c.

Flow in Pipes.—Darcy, a French engineer, made a series of experiments on different diameters of cast-iron pipe, with different degrees of internal

roughness, from which he calculated a series of formulas. The following are some of these formulas, as arranged by Mr. E. Sherman Gould, C. E., E. M., one of the most experienced hydraulic engineers in America. Darcy found that the character of the inside surface of the pipe played a very important part in its discharge, and he deduced a formula and determined a series of coefficients for it, but Mr. Gould calls attention to the fact that the coefficients for pipes from 8″ to 48″ in diameter practically cancel the numerical factor employed in Darcy's formula, and that a slightly different factor applies to pipes from 3 to 8 in., so that we may have the following simple formulas, in which the factors given apply:

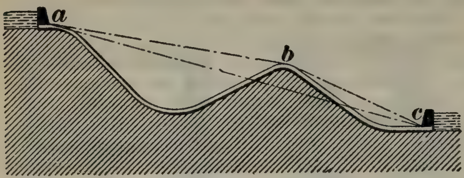


FIG. 15.

Q = amount of water in cubic feet per second;
q = U. S. gallons per minute;
D = diameter of pipe in feet;
d = diameter of pipe in inches;
H = total head in feet;
h = head per 1,000 ft.;
V = velocity in feet per second.

Pipes above 8 in. in diameter, rough inside surface,

$$Q = \sqrt{D^5 h} = D^2\sqrt{D h}; \quad V = 1.27\sqrt{D h}.$$

For diameter in inches, $Q = \frac{d^2}{288}\sqrt{\frac{d h}{3}}$.

Pipes between 3 and 8 in. in diameter, rough inside surface,

$$Q = 0.89\sqrt{D^5 h} = 0.89\, D^2\sqrt{D h}; \quad V = 1.13\sqrt{D h}.$$

Large pipes, smooth inside surface,

$$Q = 1.4\sqrt{D^5 h} = 1.4\, D^2\sqrt{D h}; \quad V = 1.78\sqrt{D h}.$$

Small pipes, smooth inside surface,

$$Q = 0.89\sqrt{2\, D^5 h} = 1.25\, D^2\sqrt{D h}; \; V = 1.6\sqrt{D h}.$$

As a rule, it is best to calculate any pipe line by the formula for pipes having a rough internal surface, for if this is not done the results are liable to be disappointing, since all pipes become more or less rough with use.

Eytelwein's Formula for the Delivery of Water in Pipes:

D = diameter of pipe in inches;
H = head of water in feet;
L = length of pipe in feet;
W = cubic feet of water discharged per minute

$$W = 4.71\sqrt{\frac{D^5 H}{L}}. \qquad D = .538\sqrt[5]{\frac{L \times W^2}{H}}.$$

Hawksley's Formula:

G = number of gallons delivered per hour;
L = length of pipe in yards;
H = head of water in feet;
D = diameter of pipe in inches.

$$D = \tfrac{1}{15}\sqrt[5]{\frac{G L}{H}}. \quad G = \sqrt{\frac{(15\, D)^5 H}{L}}$$

Neville's General Formula:

v = velocity in feet per second;
r = hydraulic mean depth in feet;
s = sine of inclination, or total fall divided by total length.

$$v = 140\sqrt{r s} - 11\sqrt[3]{r s}.$$

In cylindrical pipes, v multiplied by $47.124\, d^2$ gives the discharge per minute in cubic feet, or v multiplied by $293.7286\, d^2$ gives the discharge per minute in gallons, d being the diameter of the pipe *in feet.*

COMPARISON OF FORMULAS.

R = mean hydraulic depth in feet = area ÷ wet perimeter = $\frac{d}{4}$ for circular section of pipe;

S = sine of slope = $\frac{H}{L}$;

v = velocity in feet per second;
d = diameter of pipe in feet;
L = length of pipe in feet;
H = head of water in feet.

Prony, $v = 97.05\sqrt{RS} - .08$; or, $v = 99.88\sqrt{RS} - .154$.

Eytelwein, $v = 50\sqrt{\frac{dH}{L + 50d}}$.

Eytelwein, $v = 108\sqrt{RS} - .13$.

Hawksley, $v = 48\sqrt{\frac{dH}{L + 54d}}$.

Neville, $v = 140\sqrt{RS} - 11\sqrt[3]{RS}$.

Darcy, $v = C\sqrt{RS}$; for value of C, see following Table.

Diameter of pipe (inches)	½	1	2	3	4	5	6	7	8
Value of C	65	80	93	99	102	103	105	106	107
Diameter of pipe (inches)	9	10	12	14	16	18	20	22	24
Value of C	108	109	109.5	110	110.5	110.7	111	111.5	111.5

Maximum value of C for very large pipes, 113.3.

Kutter, $v = C\sqrt{RS}$,

where
$$C = \frac{181 + \frac{.00281}{S}}{1 + \frac{.026}{\sqrt{d}}\left(41.6 + \frac{.00281}{S}\right)}.$$

Weisbach, $h = \frac{L}{r}\left(.0036 + \frac{.0043}{\sqrt{v}}\right)\frac{v^2}{2g}$,

where h = head necessary to overcome the friction in a pipe; r = the mean radius of the pipe in feet; and g = gravity = 32.2.

Darcy, $h = \frac{.02L}{d}\left(1 + \frac{1}{12d}\right)\frac{v^2}{2g}$.

Siphons.—When any part of the pipe line rises above the source of supply, such a line is called a *siphon*. If this rise is greater than the height of the water barometer (34 ft. at sea level), water will not flow through the siphon. The flow through the siphon will be the same as that through any pipe line so long as there is no accumulation of air at the highest point of the line; but such an accumulation will decrease or entirely stop the flow. All siphons should be provided at their highest points with valves for discharging the air and introducing water to fill the siphon, and it is usually best to trap the lower end of the pipe so that air cannot enter it, and to enlarge the upper end so as to reduce the loss of the stream in entering. For a siphon to work well, the fall between the intake and the discharge end should be considerable, if the rise amounts to much.

TABLE SHOWING THE ACTUAL AMOUNT, OR 80% OF THE THEORETICAL FLOW IN PIPES FROM ⅜ IN. TO 30 IN. DIAMETER.
(*Supplement to "Industry," No. 45, April, 1892.*)

Fall or Slope.	Inside Diameter of Pipes. Inches.																						
	⅜	½	¾	1	1¼	1½	1¾	2	2½	3	4	5	6	7	8	9	10	11	12	15	18	24	30
1 in 1,000	.05	.11	.32	.7	1.2	2.0	3.0	4.2	7.6	12.3	26	46	74	111	156	212	279	356	446	793	1,267	2,652	4,698
2 in 1,000	.08	.17	.50	1.0	1.9	3.0	4.6	6.5	11.6	18.6	39	69	111	166	234	316	415	530	663	1,174	1,873	3,909	6,911
3 in 1,000	.10	.22	.64	1.3	2.4	3.9	5.8	8.2	14.7	23.6	49	88	140	209	294	398	522	666	832	1,473	2,347	4,891	8,638
4 in 1,000	.13	.27	.77	1.6	2.9	4.6	6.9	9.8	17.4	27.9	58	103	165	246	346	468	613	782	977	1,727	2,751	5,727	10,109
5 in 1,000	.14	.31	.88	1.8	3.3	5.4	7.9	11.1	19.8	31.7	66	117	187	278	392	530	694	885	1,105	1,956	3,110	6,470	11,415
6 in 1,000	.16	.34	.98	2.0	3.6	5.9	8.7	12.4	22.0	35.2	73	130	208	308	434	586	767	979	1,222	2,159	3,426	7,145	12,601
7 in 1,000	.18	.38	1.08	2.2	4.0	6.4	9.6	13.5	23.3	38.4	80	142	226	335	473	639	833	1,066	1,331	2,349	3,737	7,769	13,772
8 in 1,000	.19	.41	1.17	2.4	4.3	6.9	10.3	14.6	25.9	41.4	86	153	244	362	509	687	899	1,147	1,432	2,527	4,019	8,351	14,720
9 in 1,000	.21	.44	1.24	2.6	4.6	7.4	11.1	15.6	27.7	44.2	92	163	260	386	543	733	959	1,223	1,522	2,694	4,284	8,900	15,684
1 in 100	.22	.46	1.33	2.7	4.9	7.9	11.7	16.6	29.4	46.9	98	173	277	408	575	777	1,016	1,298	1,617	2,853	4,536	9.421	16,599
2 in 100	.33	.70	1.98	4.1	7.3	11.7	17.4	24.5	43.3	69.1	144	254	404	598	840	1,134	1,482	1,888	2,355	4,149	6,653	13,664	23,993
3 in 100	.42	.88	2.50	5.2	9.2	14.7	21.8	30.7	54.3	86.3	179	317	504	749	1,046	1,411	1,844	2,348	2,928	5,157	8,184	16,958	29,828
4 in 100	.50	1.04	2.94	6.1	10.8	17.2	25.5	35.9	63.5	101.1	210	370	588	870	1,222	1,647	2,152	2,740	3,416	5,998	9,539	19,754	34,732
5 in 100	.56	1.18	3.33	6.9	12.2	19.5	28.9	40.6	71.7	114.1	237	418	663	981	1,377	1,856	2,424	3,082	3,838	6,769	10,738	22,228	39,073
6 in 100	.62	1.31	3.68	7.6	13.5	21.6	31.9	44.9	79.2	126.0	261	461	732	1,082	1,518	2,046	2,665	3,401	4,239	7,457	11,826	24,474	43,011
7 in 100	.68	1.42	4.01	8.3	14.7	23.5	34.7	48.8	86.1	137.7	284	500	795	1,175	1,648	2,221	2,900	3,691	4,601	8,091	12,830	26,545	46,642
8 in 100	.73	1.53	4.32	9.0	15.8	25.2	37.4	52.5	92.6	147.2	305	537	854	1,262	1,765	2,384	3,113	3,962	4,938	8,683	13.766	28,477	50,029
9 in 100	.79	1.64	4.60	9.6	16.9	26.9	39.8	56.0	98.7	156.8	325	572	909	1,343	1,874	2,538	3,314	4,217	5,256	9,240	14,648	30,296	53,218
1 in 10	.83	1.36	4.89	10.1	17.9	28.5	42.2	59.2	104.5	165.9	344	606	959	1,421	1,992	2,684	3,504	4,459	5,557	9,768	15,484	32,018	56,238
2 in 10	1.22	2.54	7.13	14.8	26.1	41.5	61.3	86.0	151.5	239.9	498	876	1,389	2,051	2,884	3,871	5,051	6,425	8,004	14,059	22,273	46,016	80,770
3 in 10	1.52	3.17	8.89	18.4	32.4	51.5	76.2	106.6	188.4	298.2	617	1,085	1,720	2,539	3,557	4,789	6,246	7,947	9,899	17,380	27,524	56,839	99,731
4 in 10	1.78	3.71	10.37	21.5	37.8	59.9	88.8	124.5	219.0	347.3	718	1,262	2,001	2,953	4,134	5,568	7,262	9,234	11,504	20,192	31,972	66,005	115,785
5 in 10	2.01	4.18	11.69	24.2	42.6	67.7	99.9	140.1	246.4	390.7	808	1,419	2,248	3,319	4,647	6,256	8,161	10,365	12,923	22,679	35,903	74,102	129,971
6 in 10	2.22	4.61	12.89	26.6	47.0	74.5	110.1	154.3	271.3	430.1	824	1,561	2,474	3,651	5,113	6,881	8,974	11,411	14,209	24,932	39,465	81,442	142,825
7 in 10	2.41	5.01	14.00	29.0	51.0	80.9	119.4	167.4	294.2	466.4	964	1,692	2,682	3,957	5,540	7,456	9,724	12,364	15,391	27,009	42,641	88,204	154,668
8 in 10	2.59	5.38	15.00	31.1	54.7	86.8	128.2	179.6	315.7	500.0	1,033	1,815	2,876	4,242	5,940	7,993	10,423	13,252	16,501	28,946	45,811	94,508	165,708
9 in 10	2.76	5.73	15.98	33.1	58.2	92.4	136.4	191.1	335.8	532.0	1,099	1,931	3,058	4,510	6,315	8,499	11,081	14,088	17,540	30,767	48,690	100,438	176,090
10 in 10	2.92	6.06	16.92	35.0	61.6	97.6	144.2	202.0	354.9	562.0	1,162	2,040	3,230	4,764	6,671	8,975	11,704	14,880	18,525	32,492	51,416	106,052	185,902

The quantities above are American gallons per minute. For cubic feet, divide by 7.5.

LOSS OF HEAD IN PIPE BY FRICTION

In each 100 ft. in length of different diameters, when discharging the following quantities of water per minute, as given by Pelton Water Wheel Co.

INSIDE DIAMETER OF PIPE. INCHES.

Velocity. Ft. per Sec.	1		2		3		4		5		6	
	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.
2.0	2.37	.65	1.185	2.62	.791	5.89	.593	10.4	.474	16.3	.395	23.5
2.2	2.80	.73	1.404	2.88	.936	6.48	.702	11.5	.561	18.0	.468	25.9
2.4	3.27	.79	1.639	3.14	1.093	7.07	.819	12.5	.650	19.6	.547	28.2
2.6	3.78	.86	1.891	3.40	1.260	7.65	.945	13.6	.757	21.3	.631	30.6
2.8	4.32	.92	2.160	3.66	1.440	8.24	1.080	14.6	.864	22.9	.720	32.9
3.0	4.89	.99	2.440	3.92	1.620	8.83	1.220	15.7	.978	24.5	.815	35.3
3.2	5.47	1.06	2.730	4.18	1.820	9.42	1.370	16.7	1.098	26.2	.915	37.7
3.4	6.09	1.12	3.050	4.45	2.040	10.00	1.520	17.8	1.220	27.8	1.021	40.0
3.6	6.76	1.19	3.380	4.71	2.260	10.60	1.690	18.8	1.350	29.4	1.131	42.4
3.8	7.48	1.26	3.740	4.97	2.490	11.20	1.870	19.9	1.490	31.0	1.250	44.7
4.0	8.20	1.32	4.100	5.23	2.730	11.80	2.050	20.9	1.640	32.7	1.370	47.1
4.2	8.97	1.39	4.490	5.49	2.980	12.30	2.240	22.0	1.790	34.3	1.490	49.5
4.4	9.77	1.45	4.890	5.76	3.250	12.90	2.430	23.0	1.950	36.0	1.620	51.8
4.6	10.60	1.52	5.300	6.02	3.530	13.50	2.640	24.0	2.110	37.6	1.760	54.1
4.8	11.45	1.58	5.720	6.28	3.810	14.10	2.850	25.1	2.270	39.2	1.900	56.5
5.0	12.33	1.65	6.170	6.54	4.110	14.70	3.080	26.2	2.460	40.9	2.050	58.9
5.2	13.24	1.72	6.620	6.80	4.410	15.30	3.310	27.2	2.650	42.5	2.210	61.2
5.4	14.20	1.78	7.100	7.06	4.730	15.90	3.550	28.2	2.840	44.2	2.370	63.6
5.6	15.16	1.85	7.580	7.32	5.060	16.50	3.790	29.3	3.030	45.8	2.530	65.9
5.8	16.17	1.91	8.090	7.58	5.400	17.10	4.040	30.3	3.240	47.4	2.700	68.3
6.0	17.23	1.98	8.610	7.85	5.740	17.70	4.310	31.4	3.450	49.1	2.870	70.7
7.0	22.89	2.31	11.450	9.16	7.620	20.60	5.720	36.6	4.570	57.2	3.810	82.4

INSIDE DIAMETER OF PIPE. INCHES.

Velocity. Ft. per Sec.	7		8		9		10		11		12	
	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.
2.0	.338	32.0	.296	41.9	.264	53.0	.237	65.4	.216	79.2	.198	94.2
2.2	.401	35.3	.351	46.1	.312	58.3	.281	72.0	.255	87.1	.234	103.0
2.4	.468	38.5	.410	50.2	.365	63.6	.327	78.5	.297	95.0	.273	113.0
2.6	.540	41.7	.473	54.4	.420	68.9	.378	85.1	.344	103.0	.315	122.0
2.8	.617	44.9	.540	58.6	.480	74.2	.432	91.6	.392	111.0	.360	132.0
3.0	.698	48.1	.611	62.8	.544	79.5	.488	98.2	444	119.0	.407	141.0
3.2	.785	51.3	.686	67.0	.609	84.8	.549	105.0	.499	127.0	.457	151.0
3.4	.875	54.5	.765	71.2	.680	90.1	.612	111.0	.557	134.0	.510	160.0
3.6	.969	57.7	.848	75.4	.755	95.4	.679	118.0	.617	142.0	.566	169.0
3.8	1.070	60.9	.936	79.6	.831	101.0	.749	124.0	.680	150.0	.624	179.0
4.0	1.175	64.1	1.027	83.7	.913	106.0	.822	131.0	.747	158.0	.685	188.0
4.2	1.280	67.3	1.122	87.9	.998	111.0	.897	137.0	.816	166.0	.749	198.0
4.4	1.390	70.5	1.220	92.1	1.086	116.0	.977	144.0	.888	174.0	.815	207.0
4.6	1.510	73.7	1.320	96.3	1.177	122.0	1.059	150.0	.963	182.0	.883	217.0
4.8	1.630	76.9	1.430	100.0	1.270	127.0	1.145	157.0	1.040	190.0	.954	226.0
5.0	1.760	80.2	1.540	105.0	1.370	132.0	1.230	163.0	1.122	198.0	1.028	235.0
5.2	1.890	83.3	1.650	109.0	1.470	138.0	1.320	170.0	1.200	206.0	1.104	245.0
5.4	2.030	86.6	1.770	113.0	1.570	143.0	1.410	177.0	1.280	214.0	1.183	254.0
5.6	2.170	89.8	1.890	117.0	1.680	148.0	1.510	183.0	1.370	222.0	1.260	264.0
5.8	2.310	93.0	2.010	121.0	1.800	154.0	1.610	190.0	1.460	229.0	1.340	273.0
6.0	2.460	96.2	2.150	125.0	1.920	159.0	1.710	196.0	1.560	237.0	1.430	283.0
7.0	3.260	112.0	2.850	146.0	2.520	185.0	2.280	229.0	2.070	277.0	1.910	330.0

EXAMPLE.—Have 200 ft. head and 600 ft. of 11″ pipe, carrying 119 cu. ft. of water per minute. To find effective head: In right-hand column, under 11″ pipe, find 119 cu. ft. Opposite this will be found the coefficient of friction for this amount of water, which is .444. Multiply this by the number of hundred feet of pipe, which is 6, and you will have 2.66 ft., which is the loss of head. Therefore, the effective head is $200 - 2.66 = 197.34$.

LOSS OF HEAD IN PIPE BY FRICTION

In each 100 ft. in length of different diameters, when discharging the following quantities of water per minute, as given by Pelton Water Wheel Co.

INSIDE DIAMETER OF PIPE. INCHES.

Velocity. Ft. per Sec.	13		14		15		16		18		20	
	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.
2.0	.183	110	.169	128	.158	147	.147	167	.132	212	.119	262
2.2	.216	121	.200	141	.187	162	.175	184	.156	233	.140	288
2.4	.252	133	.234	154	.218	176	.205	201	.182	254	.164	314
2.6	.290	144	.270	167	.252	191	.236	218	.210	275	.189	340
2.8	.332	156	.308	179	.288	206	.270	234	.240	297	.216	366
3.0	.375	166	.349	192	.325	221	.306	251	.271	318	.245	393
3.2	.422	177	.392	205	.366	235	.343	268	.305	339	.275	419
3.4	.471	188	.438	218	.408	250	.383	284	.339	360	.306	445
3.6	.522	199	.485	231	.452	265	.425	301	.377	382	.339	471
3.8	.576	210	.535	243	.499	280	.468	318	.416	403	.374	497
4.0	.632	221	.587	256	.548	294	.513	335	.456	424	.410	523
4.2	.691	232	.641	269	.598	309	.561	352	.499	445	.449	550
4.4	.751	243	.698	282	.651	324	.611	368	.542	466	.488	576
4.6	.815	254	.757	295	.707	339	.662	385	.588	488	.529	602
4.8	.881	265	.818	308	.763	353	.715	402	.636	509	.572	628
5.0	.949	276	.881	321	.822	368	.770	419	.685	530	.617	654
5.2	1.020	287	.947	333	.883	383	.828	435	.736	551	.662	680
5.4	1.092	298	1.014	346	.947	397	.888	452	.788	572	.710	707
5.6	1.167	309	1.083	359	1.011	412	.949	469	.843	594	.758	733
5.8	1.245	321	1.155	372	1.078	427	1.011	486	.899	615	.809	759
6.0	1.325	332	1.229	385	1.148	442	1.076	502	.957	636	.861	785
7.0	1.750	387	1.630	449	1.520	515	1.430	586	1.270	742	1.143	916

INSIDE DIAMETER OF PIPE. INCHES.

Velocity. Ft. per Sec.	22		24		26		28		30		36	
	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.	Loss of Head. Ft.	Cu. Ft. per Min.
2.0	.108	316	.098	377	.091	442	.084	513	.079	589	.066	848
2.2	.127	348	.116	414	.108	486	.099	564	.093	648	.078	933
2.4	.149	380	.136	452	.126	531	.116	616	.109	707	.091	1,018
2.6	.171	412	.157	490	.145	575	.134	667	.126	766	.104	1,100
2.8	.195	443	.180	528	.165	619	.153	718	.144	824	.119	1,188
3.0	.222	475	.204	565	.188	663	.174	770	.163	883	.135	1,273
3.2	.249	507	.229	603	.211	708	.195	821	.182	942	.152	1,357
3.4	.278	538	.255	641	.235	752	.218	872	.204	1,001	.169	1,442
3.6	.308	570	.283	678	.261	796	.242	923	.226	1,060	.188	1,527
3.8	.340	601	.312	716	.288	840	.267	974	.249	1,119	.207	1,612
4.0	.373	633	.342	754	.315	885	.293	1,026	.273	1,178	.228	1,697
4.2	.408	665	.374	791	.345	929	.320	1,077	.299	1,237	.249	1,782
4.4	.444	697	.407	829	.375	973	.348	1,129	.325	1,296	.271	1,866
4.6	.482	728	.441	867	.407	1,017	.378	1,180	.353	1,355	.294	1,951
4.8	.521	760	.476	905	.440	1,062	.409	1,231	.381	1,414	.318	2,036
5.0	.561	792	.513	942	.474	1,106	.440	1,283	.411	1,472	.342	2,121
5.2	.602	823	.552	980	.510	1,150	.473	1,334	.441	1,531	.368	2,206
5.4	.645	855	.591	1,018	.546	1,194	.507	1,385	.473	1,590	.394	2,291
5.6	.690	887	.632	1,055	.583	1,239	.542	1,437	.506	1,649	.421	2,376
5.8	.735	918	.674	1,093	.622	1,283	.578	1,488	.540	1,708	.450	2,460
6.0	.782	950	.717	1,131	.662	1,327	.615	1,539	.574	1,767	.479	2,545
7.0	1.040	1,109	.953	1,319	.879	1,548	.817	1,796	.762	2,061	.636	2,968

The following formula, deduced by William Cox, gives practically the same results as the foregoing table and will be found useful in many instances: $F = \frac{L}{1{,}000\,D}(4V^2 + 5V - 2)$, where F = friction head; L = length of pipe in feet; D = diameter of pipe in inches; V = velocity in feet per second.

Friction of Knees and Bends.—This subject has not been investigated sufficiently to enable the engineer to make exact allowance for this factor, but

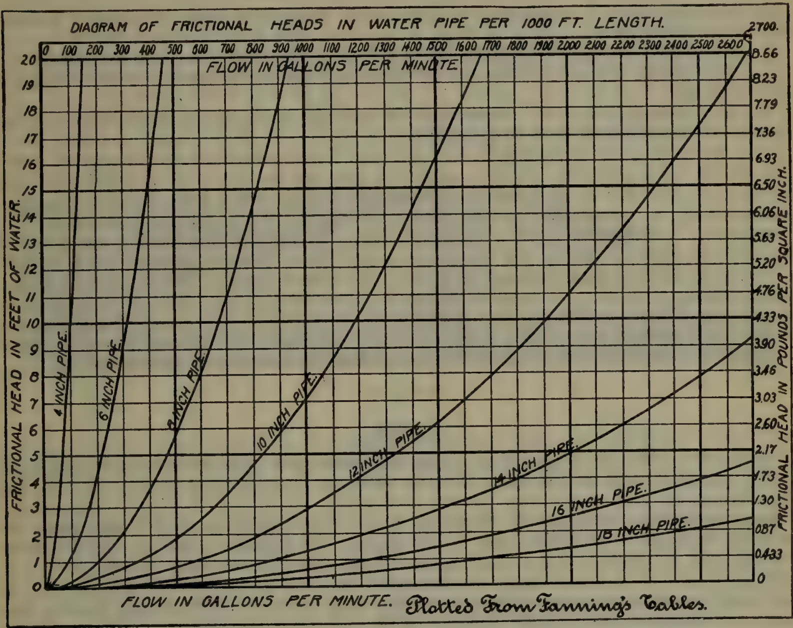


FIG. 16.

the following formulas may be taken as giving close approximate results. It is well to bear in mind that right angles should be avoided whenever possible, and that bends should be made with as large a radius as circumstances will allow.

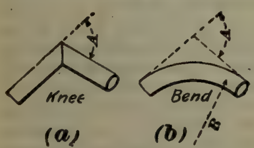


FIG. 17.

A = angle of bend or knee with forward line of direction;
V = velocity of water in feet per second;
R = radius of center line of bend;
r = radius of bore of pipe (or $\frac{1}{2}$ diameter);
K = coefficient for angles of knees;
L = coefficient for curvature of bends;
H = head of water in feet necessary to overcome the friction of the bends, or knees.

$$H = .0155\ V^2K.$$

The value of K is as follows for different angles:

$A°$ =	20°	40°	60°	80°	90°	100°	120°
K =	.046	.139	.364	.74	.98	1.26	1.86

For bends, $$H = .0155\ V^2 \left(\frac{A}{180} L\right).$$

Values of L with various ratios of the radius of bend to radius of bore:

When $\frac{r}{R}=$	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
In circular section L	.131	.138	.158	.206	.294	.44	.66	.98	1.4	2.0
In rectangular L	.124	.135	.18	.25	.4	.64	1.01	1.55	2.3	3.2

RESERVOIRS.

Reservoir Site.—In selecting a site for a reservoir, the following points should be observed:

1. A proper elevation above the point at which the water is required.
2. The total supply available, including observations as to the rainfall and snowfall.
3. The formation and character of the ground, with reference to the amount of absorption and evaporation.

The most desirable formation of ground for a reservoir site is one of compact rock, like granite, gneiss, or slate; porous rocks, like sandstones and limestones, are not so desirable. Steep bare slopes are best for the country surrounding a reservoir, as the water escapes from them quickly. The presence of vegetation above the reservoir causes a considerable amount of absorption; but, at the same time, the rainfall is usually greater in a region covered with vegetation than in a barren region, hence the streams have a more uniform flow. A reservoir must be made large enough to hold a supply capable of meeting the maximum demand. The area of a reservoir should be determined, and a table made showing its contents for every foot in depth, so that the amount of water available can always be known.

DAMS.

Dams are used for retaining water in reservoirs, for diverting streams in placer mining, and for storing débris coming from placer mines in cañons or ravines.

Foundations for dams must be solid to prevent settling, and water-tight to prevent leakage under the base of the dam. Whenever possible, the foundation should be solid rock. Gravel is better than earth, but when gravel is employed it will be necessary to drive sheet piling under the upper toe of the dam, to prevent water from seeping through the formation under the dam. Vegetable soil should be avoided, and all porous material, such as sand, gravel, etc. should be stripped off until hard pan or solid rock is reached. In case springs occur in the area covered by the foundation of the dam, it will be necessary to trace them up, and if they originate on the upper side to confine their flow to that side of the dam, so that they will have no tendency to ultimately become passageways for water from the upper face to the lower face of the dam, thus providing holes which may ultimately destroy the entire foundation of the structure.

Wooden Dams.—Wooden dams are constructed of round, sawed, or hewn logs. The timbers are usually at least 1 ft. square, or, if round, from 18 to 24 in. in diameter. A series of cribs from 8 to 10 ft. square are constructed by building up the logs log-house fashion and securing them together with treenails. The individual cribs are secured to one another with treenails or by means of bolts. The cribs are usually filled with loose rock to keep them in place, and in many cases are secured to the foundation by means of bolts. A layer of planking on the upper face of the dam makes it water-tight, and if the spillway is over the crest of the dam it will be necessary to plank the top of the cribs, and, in most cases, to provide an apron for the water to fall on. The apron may be set on small cribs, or on timbers projecting from the cribs of the dam itself.

Abutments and Discharge Gates.—Abutments are structures at the ends of a dam. They may be constructed from timber, masonry, or dry stonework. If possible, abutments should have a curved outline, and should be so placed that there is no possibility of the water overflowing them, or getting behind them during floods. If the regular discharge from a dam takes place from the main face, the gates may be arranged in connection with one of the abutments, or by means of a tunnel and culvert through the dam. In

either case, some structure should be constructed above the outlet so as to prevent driftwood, brush, and other material from stopping the discharge gates. When the discharge gates are placed at one side of the dam, they are usually arranged outside of the regular abutment, between it and another special abutment, the discharge being through a series of gates into a flume, ditch, or pipe.

Spillways or Waste Ways.—These are openings provided in a dam for the discharge of water during floods or freshets, or for the discharge of a portion not being used at any time. The spillway may be over the crest of the dam, or, where the topography favors such a construction, the main dam may be of sufficient height to prevent water from ever passing its crest, the spillway being arranged at another outlet over the lower dam. Waste ways, proper, are openings through the dam, and are intended for the discharge of the large quantities of water that come down during freshets or floods. In the case of timber dams, the waste ways are usually surrounded by heavy cribs, and have an area of from 40 to 50 sq. ft. each. There are two general forms of construction employed for waste ways. One consists of a comparatively narrow opening in the dam, extending to a considerable depth (8 or

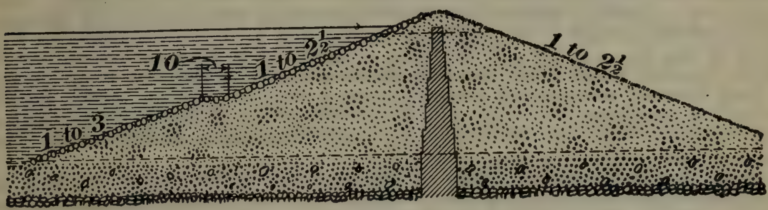


FIG. 18.

10 ft.). Water is allowed to discharge through this during flood time, but when it is desired to stop, the flow planks are placed across the up-stream face of the opening in such a manner as to close it. The opening, which is usually not over 3 or 4 ft. wide, is provided with guides on the upper face of the dam, and between which the planks are slid down, the individual pieces of planking being at least 1 ft. longer than the opening that they are to cover. The other device frequently used consists in providing the waste way, at one side of the regular spillway, with a crest 2 or 3 ft. lower than the regular spillway. The crest of this waste way is composed of heavy timber, and 4 or 5 ft. above there is arranged a parallel timber, the space between the two being closed by what are called flash boards. These are made from pieces of 2″ or 3″ plank, 6 or 8 in. wide. The planks are placed against both timbers so as to close the space. The individual planks are made long enough so that they extend from 1 to 2 ft. above the upper timber, and through the upper end of each plank is bored a hole through which a piece of rope is passed and a knot tied in the end of the rope. These ropes are secured by staples to the upper timber. When it becomes necessary to open the waste way, men go under with peevies, cant hooks, or pinch bars, and pry up the planks in such a way as to draw the longer end out of contact with the lower timber, when the force of the water will immediately carry the plank down the stream as far as the rope will allow it to go. After the first plank has been loosened, the succeeding ones can be pulled up with comparative ease, and two men can open a 25′ or 30′ section of waste way in a very few minutes. The ropes keep the plank from being lost, and the opening can be closed again by passing the plank down into the water to one side of the opening and moving them into the current. Some skill is required, both in opening and closing the waste ways.

Stone Dams.—Where cement or lime is expensive, and suitable rubble stone can be obtained, dams are frequently constructed without the use of mortar. The upper and lower faces of the dam should be of hammer-dressed stone, carefully bonded, and the stones in the lower face of the dam are sometimes anchored by means of bolts. The dam can be made water-tight by means of a skin of planking on the upper face. In case water should ever pass over the crest of such a dam, much of it would settle through the openings in the stone into the interior of the dam, and this would subject the stones in the lower portion of the face to a hydrostatic

pressure, provided an opening was not made for the escape of such water. For this reason, culverts or openings should be made through the lower portion of the dam, to discharge any such water. When such dams as this are constructed, the regular spillway is not placed over the face of the dam, but at some other point, and usually over a timber dam.

Earth Dams.—Earth dams are used for reservoirs of moderate height. They should be at least 10 ft. wide on top, and a height of more than 60 ft. is unusual. When the material of which the dam is composed is not water-tight, as, for instance, gravel, sand, etc., it is sometimes necessary to construct a puddle wall of clay in the center of the regular dam. This consists of a narrow dam of clay mixed with a certain proportion of sand. The puddle wall should not be less than from 6 to 8 ft. thick at the top of the dam, and should be given a slight batter on each side. It is constructed during the building of the dam, and should be protected from contact with the water by a considerable thickness of earth on the upper face. The upper face of an earthen dam is frequently protected by means of plank or a pavement of stone. The lower face is frequently protected by means of sod, or sod and willow trees. Sometimes earth dams are provided with a masonry core in place of the puddle wall, to render them water-tight. This consists of a masonry wall carried to an impervious stratum, and up through the center of the dam. The masonry core should never be less than 2 or 3 ft. thick at the top, and should be given a batter of at least 10% on each side. At the regular water level, earthen dams are liable to have a small bench or shelf formed, and on this account, during the construction, such a bench or shelf is sometimes built into the earth dam. Fig. 18 shows a dam with a masonry core, with the upper face covered with rubble and the lower face covered with grass.

Débris Dams.—These are dams or obstructions placed across the bed of streams to hold back tailings from mines, and to prevent damage to the valleys below. They are made of stone, timber, or brush. No attempt is made to render the débris dam water-tight, the only object being that it should retard the flow of the stream and give it a greater breadth of discharge, so that the water naturally drops and deposits the sediment that it is carrying. The sediment soon silts or fills up against the face of the dam, the area above the dam becoming a flat expanse or plain over which the water finds its way to the dam. When these dams are constructed of stone, the individual stones on the lower face and crest of the dam should be so large that the current will be unable to displace them, while the upper face and core of the dam may be composed of finer material. In case a breach should occur in the débris dam, it will not necessarily endanger the region farther down the stream, as is the case when a break occurs in a water dam. The reason for this is that the débris dam is not made water-tight, and hence there is never much pressure against it, or a large volume of water held back that can rush suddenly down the stream should a break occur. The only result of the break would be that more or less of the gravel behind the dam would be washed through the breach.

Wing Dams.—Wing dams are used for turning streams from their courses, so as to expose all or a portion of the bed for placer mining or other purposes. They are usually of a temporary nature, and are constructed of brush and stones, light cribs filled with stones, and of large stones, or timber. Sometimes the course of a stream is turned by an obstruction made of sand bags, and a wing dam constructed behind this of frames of timber, the intervening space being filled with gravel or earth, and, in some cases, the timber being covered with stone, and the surface riprapped so that if the flow ever comes over the top of the structure it will not destroy it.

Masonry Dams.—When high masonry dams are to be employed they should be designed by a competent hydraulic engineer. Masonry dams are not, as a rule, used for hydraulic mining, owing to the fact that the length of time during which the dam is required rarely warrants the expense of the construction of a masonry dam.

WATER-POWER.

The Theoretical Efficiency of the Water-Power.—The gross power of a fall of water is the product of the weight of water discharged in a unit of time, and the total head or difference in elevation of the surface of the water, above and below the fall. The term head, used in connection with waterwheels,

is the difference in height between the surface of water in the penstock and that in the tailrace, when the wheel is running.

If Q = cubic feet of water discharged per minute,
W = weight of a cubic foot of water = 62.5 lb.,
and H = total head in feet,
then WQH = gross power in foot-pounds per minute,
and $\frac{WQH}{33,000}$ = the horsepower.

Substituting the value for W, we have

$$\frac{QH \times 62.5}{33,000} = .00189\,QH, \text{ as the horsepower of a fall.}$$

The total power can never be utilized by any form of motor, owing to the fact that there is a loss of head, both at the entrance to, and exit from, the wheel, and there are also losses of energy, due to friction of the water in passing through the wheel. The ratio of the power developed by the wheel to the gross power of the fall, is the efficiency of the wheel. A head of water can be made use of in any one of the following ways:

1. By its weight, as in the water balance, or overshot wheel.
2. By its pressure, as in the hydraulic engine, hydraulic presses, cranes, etc., or in a turbine water wheel.
3. By its impulse, as in the undershot and impulse wheels, such as Peltons, etc.
4. By a combination of the above.

The Horsepower of a Running Stream.—The gross horsepower, as seen above, is

$$\text{H. P.} = \frac{QH \times 62.5}{33,000} = .00189\,QH,$$

in which Q is the quantity in cubic feet per minute actually impinging on the float or bucket, and H the theoretical head added to the velocity of the stream, or

$$H = \frac{v^2}{2g} = \frac{v^2}{64.4},$$

in which v is the velocity in feet per second.

For example, if the floats of an undershot waterwheel were 2 ft. × 10 ft., and the stream had a velocity of 3 ft. per second, i. e., $v = 3$, we would have

$$H = \frac{9}{64.4} = .139, \text{ and } Q = 2 \times 10 \times 3 \times 60 = 3,600 \text{ cu. ft. per min.}$$

From this, H. P. = 3,600 × .139 × .00189 = .945 H. P., or a gross horsepower for practically .05 sq. ft. of wheel surface; but, under ordinary circumstances, it would be impossible to attain more than 40% of this, or practically .02 horsepower per sq. ft. of surface, which would require 50 sq. ft. of float surface to each horsepower furnished.

Current Motors.—A current motor fully utilizes the energy of a stream only when it is so arranged that it can take all of the velocity out of the water; that is, when the water leaves the floats or vanes with no velocity. It is evident that in practice we can never even obtain a close approximation to these results, and hence only a small fraction of the energy of a running stream can be utilized by the current motor. Current motors are frequently used to obtain small amounts of power from a large stream, as, for instance, for pumping a limited amount of water for irrigation. For this work, an ordinary undershot wheel having radial paddles is usually employed. At one end of the wheel a series of small buckets are placed, and so arranged that each bucket will dip up water at the bottom of the wheel and discharge it into the launder, near the top of the wheel. The shape of the buckets should be such that only the amount of water which the bucket is capable of carrying to the launder will be dipped up, for, if the bucket is constantly slopping or pouring water as it ascends, a large amount of useless work is performed in raising this extra water and then pouring it out again, as only the portion that reaches the launder can be of any service. Current motors are not practicable for furnishing large amounts of power.

UTILIZING THE POWER OF A WATERFALL.

The power of a waterfall may be utilized by a number of different styles of motors, but each has certain advantages.

Breast and Undershot Wheels.—When the head is low (not over 5 or 6 ft.), breast or undershot wheels are frequently employed. If these are properly

proportioned, it is possible to realize from 25% to 50% of the theoretical power of the fall, but the wheels are large and cumbersome compared with the duty they perform, and not often installed at present, especially near manufacturing centers.

Overshot Wheels.—For falls up to 40 or 50 ft., overshot wheels are very commonly employed, and they have been used for even greater heads than this. The overshot wheel derives its power both from the impulse of the water entering the buckets, and from the weight of the water as it descends on one side of the wheel in the buckets. The latter factor is by far the more important of the two. When properly proportioned, overshot wheels may realize from 70% to 90% of the power of the waterfall, but they are large and cumbersome compared with the power that they give, and are not often installed except in isolated regions, where they are made from timber by local mechanics.

Impulse Wheels.—For heads varying from 50 ft. up, impulse wheels are very largely used. These are also sometimes called *hurdy gurdies*, and are usually of the Pelton type, consisting of a wheel provided with buckets, so arranged about its periphery that they receive an impinging jet of water and turn it back upon itself, discharging it with practically no velocity, and converting practically all the energy into useful work. The efficiency of these wheels varies from 85% to 90% under favorable circumstances. This style of wheel is especially adapted for very high heads and comparatively small amounts of water. There are a number of instances where wheels are operating under a head of as much as 2,000 ft. This style of impulse wheel is an American development; in Europe, a style of impulse turbine has been used to some extent, but has not found very much favor in the United States.

Turbines.—Turbines or reaction wheels are very largely employed, especially for moderate heads. When properly designed to fit the working conditions, they can be used for heads varying from 4 or 5 ft. up to considerably over 100 ft., and when properly placed are capable of utilizing the entire head, a factor that gives them a decided advantage over any other style of waterwheel. Turbines are capable of returning 85% to 90% of the theoretical energy as useful power, and are largely used, especially where a considerable volume of water at a low head, or a smaller volume at a moderate head, can be obtained.

PUMP MACHINERY.

Pumps are employed for unwatering mines, handling water at placer mines, irrigation, water-supply systems, boiler feeds, etc.

For unwatering mines, two general systems of pumping are employed. (1) The pump is placed in the mine and is operated by a motor on the surface, the power being transmitted through a line of moving rods. (2) Both the motor and pump are placed in the mine, the motor being an engine driven by steam, compressed air, hydraulic motor, or an electric motor.

Cornish Pumps.—Any method of operating pumps by rods is commonly called a *Cornish system*. Formerly, the motor in the Cornish system consisted of a steam engine placed over the shaft head, which operated the pump by a direct line of rods. With this arrangement, there is great danger of accident to the engine from the settling of the ground around the shaft, or from fire in the shaft; also, the position of the motor renders access to the shaft difficult. To overcome these objections, the engine is frequently placed at one side of the shaft, and the rods operated by a bob; this has become the common practice, and is generally called the *Cornish rig*. The engine employed in the most modern plants is generally of the Corliss type, and is provided with a governor to guard against the possibility of the engine running away, in case the rods should break.

This system requires no steam line down the shaft, and is independent of the depth of water in the mine, so that the pump is not stopped by the drowning of a mine, but the moving rods are a great inconvenience in the shaft, and they absorb a great amount of power by friction.

Simple and Duplex Pumps.—In the simple pump, a steam cylinder is connected directly to a water cylinder, and the steam valves are operated by tappets. Such a pump is more or less dependent on inertia at certain points of the stroke to insure the motion of the valves, hence will not start from

any place, but is liable to become stalled at times. In the duplex pump, two steam cylinders and two water cylinders are arranged side by side, and the valves so placed that when one piston is at mid-stroke it throws the steam valve for the other cylinder, etc. With this arrangement, the pump will start from any point, and can never be stalled for lack of steam, due to the position of the valves. Ordinarily, duplex pumps are to be preferred for mine work.

The **packing** for the water piston of a pump may be either *inside* or *outside*. Any form of packing that is inside the cylinder, either upon a moving piston or surrounding the ram, and so situated that any wear will allow communication between the opposite ends of the cylinder, is called *inside* packing. It may consist simply of piston rings about the piston, as in the case of an ordinary steam-engine piston *G*, Fig. 19, or stationary rings may be employed about the outside of a moving ram or long piston *P*. In either case, the cylinder heads have to be removed before the condition of the packing can be inspected, and any leak does not make itself visible.

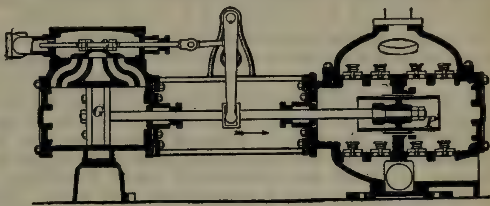


FIG. 19.

When outside packing is employed, separate rams are used in opposite ends of the cylinder, there being no internal communication between the chambers in which the rams work. The rams are packed by ordinary outside stuffingboxes and glands. The arrangement consists practically of two single-acting pumps arranged to work alternately, so that one is forcing water while the other is drawing water. Fig. 20 shows a horizontal section of a cylinder so arranged, together with the yoke rods that operate the ram at the farther end of the cylinder.

As a rule, inside-packed pumps should be avoided in mines, on account of the fact that acid or gritty waters are liable to cut the packing, and make the pumps leak in a very short time. For dipping work in single stopes or entries, small single or duplex outside-packed pumps may be employed. It is generally best to operate such pumps by compressed air, for the exhaust will then be beneficial to the mine air. If steam is employed, it is frequently necessary to introduce a trap and remove entrailed water from the steam before it enters the pump, and to dispose of the exhaust by piping it out or condensing it. Such isolated steam pumps are about the most wasteful form of steam-driven motor in existence.

For sinking, center-packed single or duplex pumps are usually employed, the duplex style being the better. For station work, where much water is to be handled, large compound, or triple-expansion, condensing, duplex pumping engines are employed. They may, or may not, be provided with cranks and a flywheel. Engineers differ greatly upon this point, and, as a rule, for very high lifts and great pressures, the flywheel is employed.

The main points in consideration are the first cost of the pump, and the amount that will be saved by using the more expensive engine. The large flywheel pumping engines are several times as expensive as the direct-acting steam pumps, and the question is as to whether their greater efficiency will more than counterbalance the increased outlay. Most engineers favor flywheel pumps for handling large volumes of water where the work is approximately constant, and direct-acting pumps, without flywheels or cranks, for handling small amounts of water, or for very irregular service, owing to the fact that if the flywheel pump is driven below its normal speed it does not govern properly, nor work economically. Until recently, water was removed from mines in lifts of about 300 to 350 ft., pumps being placed at stations along the shaft.

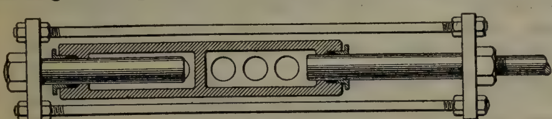


FIG. 20.

While a series of station pumps are still employed, in some cases they are

generally intended to take care of water coming into the shaft, or workings at or near their level, and are not employed for handling water in successive stages or lifts. For handling the bulk of the water from the bottom of the shaft, large pumping engines are employed that frequently force the water to the surface from depths of over 1,000 ft. These high-duty pumping plants, when near the shaft and operated by steam with a condenser, frequently show a very high efficiency. When air is employed to operate such a plant, a much higher efficiency can be obtained if the compressed air is heated before using in the high-pressure cylinder, and during its passage from the high-pressure to the low-pressure cylinder. This has been very successfully accomplished by means of a steam reheater, the small amount of steam necessary being conveyed to the station in the small pipe, and entirely condensed in the reheater, from which it is trapped as water.

The duty of steam pumps is approximately as follows: For small-sized steam pumps, the steam consumption is from 130 to 200 lb. per horsepower per hour, when operating in the workings of a mine at some distance from the boiler. For larger sizes of simple steam pumps, the consumption runs from 80 to 130 lb. of steam per horsepower per hour. Compound-condensing pumps, such as are commonly used as station pumps, consume from 40 to 70 lb. of steam per horsepower per hour. Triple-expansion, condensing, high-class pumping engines consume from 24 to 26 lb. per horsepower per hour. The Cornish pump consumes varied amounts of steam in proportion to the water delivered, depending largely on the friction of the gearing, bobs, rods, etc., but its efficiency is usually considerably below the best class of pumping engines.

Speed of Water Through Valves, Pipes, and Pump Passages.—The speed of water through the valves and passages of a pump should not exceed 250 ft. per minute, and care should be taken to see that the passages are not too abruptly deflected. The flow of water through the discharge pipe should not exceed 500 ft. per minute, but for single-cylindered pumps it is usually figured at between 250 and 400 ft. per minute. In the case of very large pumps, greater velocities may be allowed. The suction pipe for the pump should be larger than the discharge pipe. Ordinarily, the suction pipe for a pump should not exceed 250 ft. in length, and should not contain more than two elbows. The following formula gives the diameter of the suction and discharge pipes of a pump:

G = U. S. gallons per minute;
d' = diameter of suction pipe in inches;
d'' = diameter of discharge pipe in inches;

$$d' = 4.95\sqrt{\frac{G}{v'}};$$

$$d'' = 4.95\sqrt{\frac{G}{v''}}.$$

v' = velocity of water in feet per minute in the suction pipe = from $.50\,v''$ to $.75\,v''$;
v'' = velocity of water in feet per minute in the discharge pipe.

RATIO OF STEAM AND WATER CYLINDERS IN A DIRECT-ACTING PUMP.

A = area of steam cylinder;
D = diameter of steam cylinder;
P = steam pressure in pounds per square inch;
H = head of water = $2.309\,p$;
a = area of pump cylinder;
d = diameter of pump cylinder;
p = pressure per square inch, corresponding to the head $H = .433\,H$;
E = efficiency of pump = $\dfrac{\text{work done in pump cylinder}}{\text{work done in steam cylinder}}$.

$$A = \frac{a\,p}{E\,P}; \qquad d = D\sqrt{\frac{E\,P}{p}}; \qquad \frac{A}{a} = \frac{p}{E\,P} = \frac{.433\,H}{E\,P};$$

$$a = \frac{E\,A\,P}{p}; \qquad P = \frac{a\,p}{E\,A};$$

$$D = d\sqrt{\frac{p}{E\,P}}; \qquad p = \frac{E\,A\,P}{a}; \qquad H = 2.309\,E\,P \times \frac{A}{a}.$$

If $E = 75\%$, then $H = 1.732\, P \times \frac{A}{a}$.

E is commonly taken at from .7 to .8 for ordinary direct-acting pumps. For the highest class of pumping engines it may amount to .9. The steam pressure P is the mean effective pressure, according to the indicator diagram; the pressure p is the mean total pressure acting on the pump plunger or piston, including the suction, as would be shown by the indicator diagram of the water cylinder. The pressure on the pump cylinder is frequently much greater than that due to the height of the lift, on account of the friction in the valves and passages, which increases rapidly with the velocity of the flow.

Piston Speed of Pumps.—For small pumps, it is customary to assume a speed of 100 ft. per minute, but, in the case of very small short-stroke pumps, this is too high, owing to the fact that the rapid reverses make the flow through the valves and change in the direction of the current too frequent. When the stroke of the pump is somewhat longer (18 in. or more), higher speeds can be employed, and in the case of large pumping engines having long strokes, speeds of as much as 200 to 250 ft. per minute are successfully used without jar or hammer.

Boiler Feed-Pumps.—In practice, it has been shown that a piston speed greater than 100 ft. per minute results in excessive wear and tear on a boiler feed-pump, especially when the water is warm. This is due to the fact that vapor forms in the cylinders, and results in a water hammer. In determining the proper size of a pump for feeding a steam boiler, not only the steam employed in running the engine, but that necessary for the pumps, heating system, etc. must be taken into consideration.

THEORETICAL CAPACITY OF PUMPS AND THE HORSEPOWER REQUIRED TO RAISE WATER.

Let Q = cubic feet of water per minute;
G = U. S. gallons per minute;
G' = U. S. gallons per hour;
d = diameter of cylinder in inches;
l = stroke of piston in inches;
N = number single strokes per minute;
v = speed of piston in feet per minute;
W = weight moved in pounds per minute;
P = pressure in pounds per square feet = $62.5 \times H$;
p = pressure in pounds per square inch = $.433 \times H$.
H = height of lift in feet;
H. P. = horsepower.

Then,
$$Q = \frac{\pi}{4} \cdot \frac{d^2}{144} \cdot \frac{lN}{12} = .0004545\, Nd^2 l.$$

$$G = \frac{\pi}{4} \cdot \frac{Nd^2 l}{231} = .0034\, Nd^2 l. \quad G' = .204\, Nd^2 l.$$

The diameter of piston required for a given capacity per minute will be

$$d = 46.9\sqrt{\frac{Q}{Nl}} = 17.15\sqrt{\frac{G}{Nl}}, \text{ or } d = 13.54\sqrt{\frac{Q}{v}} = 4.95\sqrt{\frac{G}{v}}.$$

The actual capacity of a pump will vary from 60% to 95% of the theoretical capacity, depending on the tightness of the piston, valves, suction pipe, etc.

$$\text{H. P.} = \frac{QP}{33{,}000} = \frac{QH \times 144 \times .433}{33{,}000} = \frac{QH}{529.2} = \frac{Gp}{1{,}714.5}.$$

The actual horsepower required will be considerably greater than the theoretical, on account of the friction in the pump; hence, at least 20% should be added to the power for friction and usually about 50% more is added to cover leaks, etc., so that the actual horsepower required by the pump is about 70% more than the theoretical.

EXAMPLE 1.—If it is desired to find the size of a pump that will throw 30 gal. of water per minute up 125 ft., from the bottom of a pit or prospect shaft to the station pump at the main shaft, it may be accomplished as follows:

An allowance of probably 25% should be made with a small pump of this character, to overcome slippage or leaking through the valves, past the piston,

etc., and hence we will call the total amount of water to be handled 40 gal. per minute. The formula for the diameter of piston is

$$d = 4.95\sqrt{\frac{G}{v}}.$$

Assuming that $v = 100$ ft. per minute, we have

$$d = 4.95\sqrt{.4} = 4.95 \times .63 = 3.13.$$

In practice, a $3\frac{1}{2}''$ pump would probably be employed.

EXAMPLE 2.—If it is desired to find the approximate horsepower necessary to lift 30 gal. per minute in the above example, without determining the size of the pump, it can be done as follows:

$$\text{H. P.} = \frac{G \times p}{1{,}714.5} = \frac{30 \times .433 \times 125}{1{,}714.5} = .95, \text{ or practically 1 H. P.}$$

In order to cover leakage through valves, friction, etc., an addition of at least 75% should be made to a very small pump like this, and so we would count on $1\frac{3}{4}$ H. P.

Depth of Suction.—Theoretically, a perfect pump will raise water to a height of nearly 34 ft. at the sea level; but, owing to the fact that a perfect vacuum can never be attained with the pump, that the water always contains more or less air, and that more or less watery vapor will form below the piston, it is never possible to reach this theoretical limit, and, in practice, it is not possible to draw water much, if any, over 30 ft. at the sea level, even when the water is cold. Warm water cannot be lifted as high as cold water, owing to the fact that a larger amount of watery vapor forms. With boiler feed-pumps handling hot water, the water should flow to the pumps by gravity.

Amount of Water Raised by a Single-Acting Lift Pump.—In the case of all pumps having a piston or ram, the amount of water lifted is usually considerably less than the piston displacement, owing to the leakage through the valves, etc., but with single-acting lift pumps, having bucket plungers with a clack valve in the plunger, the amount lifted may actually exceed the plunger displacement, that is, the volume of water may actually be greater than the length of the stroke multiplied by the number of strokes, for, during the up stroke, the water both above and below the piston is set in motion, and during the down stroke, the inertia of the water actually carries more water through the valve than would pass through it on account of the space passed through. This increases as the speed or number of strokes increases.

Pump Valves.—As a rule, a large number of small valves having a comparatively small opening are preferable to a small number of large valves with a greater opening, and most modern pumps are built upon these lines. A small valve represents a proportionately larger surface of discharge with the same lift than the large valve, hence whatever the total area of the valve-seat opening, its full contents can be discharged with less lift through numerous small valves than through one large valve. Cornish pumps generally have one large metal valve.

Power Pumps.—Where comparatively small amounts of water are to be handled, and power is available, belt-driven power pumps are very much more efficient than small steam pumps.

Electrically Driven Power Pumps.—Where water is to be delivered from isolated workings to the sumps for the large station pumps, electrically driven power pumps are far more efficient than steam pumps. In some cases it is probably best to equip the entire mine with electric pumps, both in the isolated workings and at the stations, on account of the fact that they can be driven by a high-class compound-condensing engine on the surface, directly connected to a generator, and furnishing electricity through conductors to the various pumps.

The total efficiency of a series of small electric pumps that aggregate a sufficient amount of power to enable this arrangement to be used, is very much higher than the total efficiency of a number of small isolated steam or compressed-air pumps introduced into the workings. With compound-condensing engines upon the surface, operating electric pumps underground, the steam consumption per pump horsepower per hour, for the smaller sizes, would only be about 40 lb. per horsepower per hour; for medium-sized electric pumps, about 30 lb. of steam per hour, and larger sizes from 20 to 30 lb. per horsepower per hour. It will be seen from these figures that for

pumping from isolated portions of the mine the electric pump is much more efficient than the steam pump, and owing to the fact that the current can frequently be obtained from the lines operating the underground haulage system, furnishing light, etc., it is evident that this system of pumping has a great future before it in connection with mining.

The following table gives the gallons per minute delivered from various sized pumps operating at different piston speeds:

PUMP AND WATER MEMORANDA.

Diameter Cylinder.	Area. Sq. In.	Contents for 1 Ft. Length		Gallons per Minute Delivered at Indicated Piston Speeds.											
		Cubic Feet.	Gallons.	100	125	150	175	200	225	250	275	300	350	400	500
1″	.7854	.0055	.0408	4.1	5.1	6.1	7.1	8.2	9.2	10.2	11.2	12.2	14.3	16.3	20.4
2″	3.1416	.0218	.1632	16.3	20.4	24.5	28.6	32.6	36.7	40.8	44.9	49.0	57.1	65.3	81.6
3″	7.0686	.0491	.3672	36.7	45.9	55.1	64.3	73.4	82.6	91.8	101.0	110.0	129.0	147.0	183.6
4″	12.5660	.0873	.6528	65.3	71.6	87.9	104.0	121.0	137.0	153.0	170.0	186.0	228.0	261.0	306.0
5″	19.6350	.1364	1.0200	102.0	128.0	153.0	179.0	204.0	230.0	255.0	281.0	306.0	357.0	408.0	510.0
6″	28.2740	.1963	1.4690	147.0	184.0	220.0	257.0	293.0	331.0	367.0	404.0	441.0	514.0	588.0	734.0
6½″	33.1830	.2304	1.7240	172.0	216.0	259.0	302.0	345.0	388.0	431.0	474.0	517.0	603.0	690.0	862.0
7″	33.4850	.2673	1.9990	200.0	250.0	300.0	350.0	400.0	450.0	500.0	550.0	600.0	700.0	800.0	1,000.0
7½″	44.1790	.3068	2.2950	230.0	287.0	344.0	402.0	459.0	516.0	574.0	631.0	689.0	803.0	918.0	1,148.0
8″	50.2650	.3491	2.6110	261.0	326.0	392.0	457.0	522.0	588.0	653.0	718.0	783.0	914.0	1,044.0	1,306.0
8½″	56.7450	.3941	2.9480	295.0	369.0	442.0	516.0	590.0	663.0	737.0	811.0	884.0	1,032.0	1,179.0	1,474.0
9″	63.6170	.4418	3.3050	331.0	413.0	496.0	578.0	661.0	744.0	826.0	909.0	992.0	1,157.0	1,322.0	1,652.0
9½″	70.8820	.4922	3.6820	368.0	460.0	552.0	644.0	736.0	828.0	921.0	1,013.0	1,105.0	1,289.0	1,473.0	1,842.0
10″	78.5400	.5454	4.0800	408.0	510.0	612.0	714.0	816.0	918.0	1,020.0	1,122.0	1,224.0	1,428.0	1,632.0	2,040.0
10½″	86.5900	.6013	4.4980	450.0	562.0	675.0	787.0	900.0	1,012.0	1,125.0	1,237.0	1,349.0	1,574.0	1,799.0	2,250.0
11″	95.0330	.6600	4.9370	494.0	617.0	741.0	864.0	987.0	1,111.0	1,234.0	1,358.0	1,481.0	1,728.0	1,975.0	2,468.0
11½″	103.8700	.7213	5.3960	540.0	675.0	809.0	944.0	1,079.0	1,214.0	1,349.0	1,484.0	1,619.0	1,889.0	2,158.0	2,698.0
12″	113.1000	.7854	5.8750	588.0	734.0	881.0	1,028.0	1,175.0	1,322.0	1,469.0	1,616.0	1,763.0	2,056.0	2,350.0	2,938.0
12½″	122.7200	.8522	6.3750	638.0	797.0	956.0	1,116.0	1,275.0	1,434.0	1,594.0	1,753.0	1,913.0	2,231.0	2,550.0	3,188.0
13″	132.7300	.9218	6.8950	690.0	862.0	1,034.0	1,207.0	1,379.0	1,551.0	1,724.0	1,896.0	2,069.0	2,413.0	2,758.0	3,448.0
13½″	143.1400	.9940	7.4360	744.0	930.0	1,115.0	1,301.0	1,487.0	1,673.0	1,858.0	2,045.0	2,231.0	2,603.0	2,974.0	3,716.0
14″	153.9400	1.0690	7.9970	800.0	1,000.0	1,200.0	1,399.0	1,599.0	1,799.0	1,999.0	2,199.0	2,399.0	2,799.0	3,199.0	3,998.0
14½″	165.1300	1.1470	8.5780	858.0	1,072.0	1,287.0	1,501.0	1,716.0	1,930.0	2,145.0	2,359.0	2,573.0	3,002.0	3,431.0	4,290.0
15″	176.7100	1.2270	9.1800	918.0	1,148.0	1,377.0	1,607.0	1,836.0	2,066.0	2,295.0	2,525.0	2,754.0	3,213.0	3,672.0	4,590.0
15½″	188.6900	1.3100	9.8010	980.0	1,225.0	1,470.0	1,715.0	1,960.0	2,205.0	2,450.0	2,695.0	2,940.0	3,430.0	3,920.0	4,900.0
16″	201.0600	1.3960	10.4400	1,044.0	1,305.0	1,566.0	1,827.0	2,088.0	2,349.0	2,610.0	2,871.0	3,132.0	3,654.0	4,176.0	5,220.0
16½″	213.8200	1.4850	11.1100	1,111.0	1,389.0	1,667.0	1,944.0	2,222.0	2,500.0	2,778.0	3,055.0	3,333.0	3,889.0	4,444.0	5,556.0
17″	226.9800	1.5760	11.7900	1,179.0	1,474.0	1,769.0	2,063.0	2,358.0	2,653.0	2,948.0	3,242.0	3,537.0	4,127.0	4,716.0	5,896.0
17½″	240.5300	1.6700	12.4900	1,249.0	1,561.0	1,873.0	2,185.0	2,498.0	2,810.0	3,122.0	3,434.0	3,747.0	4,371.0	4,996.0	6,244.0
18″	254.4700	1.7670	13.2200	1,322.0	1,653.0	1,983.0	2,314.0	2,644.0	2,975.0	3,305.0	3,636.0	3,966.0	4,627.0	5,288.0	6,610.0
18½″	268.8000	1.8670	13.9600	1,396.0	1,745.0	2,094.0	2,443.0	2,792.0	3,141.0	3,490.0	3,839.0	4,188.0	4,886.0	5,584.0	6,980.0
19″	283.5300	1.9690	14.7300	1,473.0	1,841.0	2,210.0	2,578.0	2,946.0	3,314.0	3,683.0	4,051.0	4,419.0	5,156.0	5,892.0	7,366.0
19½″	298.6500	2.0740	15.5100	1,551.0	1,939.0	2,327.0	2,714.0	3,102.0	3,490.0	3,878.0	4,265.0	4,653.0	5,429.0	6,204.0	7,756.0
20″	314.1600	2.1820	16.3200	1,632.0	2,040.0	2,448.0	2,856.0	3,264.0	3,672.0	4,080.0	4,488.0	4,896.0	5,712.0	6,528.0	8,160.0
24″	452.3900	3.1420	23.5000	2,350.0	2,938.0	3,525.0	4,112.0	4,700.0	5,288.0	5,875.0	6,463.0	7,056.0	8,225.0	9,400.0	11,750.0

1 gal. = 231 cu. in. = .13368 cu. ft. 1 gal. of water at 39.2° = 8.33888 lb.
1 cu. ft. of water = 7.48052 gal., and weighs 62.423 lb.

MISCELLANEOUS FORMS OF WATER ELEVATORS.

Jet Pump.—In this form, the energy of the jet of water is utilized for raising a larger volume through a small distance, or a mixture of water and solid material through a short distance.

Vacuum Pump.—The pulsometer, which is the most important representative of this class, consists of two chambers in a large casting, with suitable automatic valves arranged at the top and bottom of the chambers. Steam is introduced into one of the chambers, then the valve at the top closed. This steam will condense, forming a vacuum that draws water from the suction into the chamber. When the chamber is filled with water, steam is again introduced and forces the water out through the discharge pipe. The operation is then repeated, more water being drawn in by the condensation of the steam. The two chambers work alternately, one being engaged in drawing water in while the other forces it out. The total steam efficiency of this form of pump is small, though it may actually be above that of small steam pumps employed in isolated portions of a mine. The advantages are that the pump possesses no intricate mechanism, no reciprocating parts, requires no lubrication, and is not injured by gritty or acid materials. On this account it may be employed for pumping water in concentration works, coal-washing plants, and similar places where the water is liable to contain grit or dirt.

Air-Lift Pumps.—By introducing compressed air at the bottom of a pipe submerged in any liquid, the air in the pipe rises as bubbles, and so reduces the specific gravity of the fluid in the pipe. This causes the fluid in the pipe to rise above the level of that surrounding the pipe. The difference in specific gravity can never be great, and hence the fluid can never be elevated to any considerable height without having the lower end immersed to a correspondingly great depth. On this account it is frequently necessary to drill a well considerably below the water-bearing strata, so as to obtain the proper ratio between the submerged portion of the pipe and the height to which the water is to be lifted. Some advantages of this form of pump are that there are no moving parts, no lubrication is required, and gritty material does not interfere with the operation. If the pump is constructed of suitable material, it may be employed for handling acids or solutions in electrolytic or chemical works. This style of pump is also quite extensively employed for pumping water from Artesian wells. It has not been successful as a mine pump, owing to the ratio between the part immersed and the lift.

Centrifugal Pumps.—The height of lift depends on the tangential velocity of the revolving disk of pump and the quantity of water discharged, and is proportional to the area of the discharge orifices at the circumference of the disk. The most efficient total lift for the centrifugal pump is, approximately, 17 ft., and for small lifts the centrifugal pump is much more efficient than any style of piston pump. For a given lift, the total efficiency of a centrifugal pump increases with the size of the pump. Centrifugal pumps are always designated by the size of their outlet, as, for instance, a 2″ or 4″ pump, meaning with a 2″ or 4″ discharge pipe. Centrifugal pumps are not at all effective for dealing with great heads, and hence have never come into competition with piston pumps for this class of work. For lifting large volumes of water against a low head, as in irrigation or drainage problems, they are remarkably efficient. Under the most favorable circumstances, the efficiency of the centrifugal pump may be practically 70%; that is, the pump may do an amount of work upon the water that is theoretically equal to 70% of the power furnished to the pump. Pumping engines working against high heads, and operated by the most improved class of engines, may attain an efficiency of practically 85%.

Centrifugal Pump as a Dredge.—When dredging is done by means of centrifugal pumps, a greater amount of power is necessary, and the pump has to be run at a greater speed than when pumping water, owing to the fact that the fluid being handled has a greater density than water. When dealing with fine sand, as much as 50% of the bulk of the material handled may be sand, though, as a rule, the amount of solid material in the water dredged only runs from 30% to 35% of the total.

Water Buckets.—Where only a limited amount of water collects in the mine workings, it is frequently removed by means of a special water bucket or water car during the hours that the hoisting engine would otherwise be idle. Where very large amounts of water are to be removed, it has also

been found economical to remove them by means of special water buckets. This is especially true in the case of deep shafts.

One of the best illustrations of this class of work is the Gilberton water shaft, which has been equipped at the Gilberton Colliery of the Philadelphia and Reading Coal & Iron Co. The collieries draining to this shaft require the removal of 6,000,000 gal. of water per 24 hours during the wet season, and this has to be lifted from a depth of 1,100 ft. In order to accomplish the work by means of steam pumps, it required a number of pump stations in different parts of the mine, each of which had to be attended by a pumpman, and a large number of steam lines were required in the mine. In order to remove the danger of fire caused by these steam lines, and to dispense with the large amount of labor otherwise necessary, it was decided to hoist the water, and a shaft 22 ft. × 26 ft. 8 in. outside of timbers, was sunk. This shaft contains two compartments 7 ft. × 7 ft., in which the water buckets are operated, and two compartments 7 ft. × 11 ft. 8 in. that are utilized for cages to lower men, timber, and other supplies. The water tanks employed in the special water compartments are 5 ft. 6 in. in diameter, and 14 ft. long. They are provided with a special device sliding on regular cage guides, and empty themselves automatically at the surface by means of a trip or sliding valve. Two pairs of direct-acting hoisting engines, with 45″ × 60″ cylinders, operating drums 14 ft. 8 in. in diameter by 15 ft. face, are employed. These operate the water buckets in cages by means of 2″ crucible steel ropes, at 50 revolutions per minute, which is equivalent to a piston speed of 500 ft. per minute. The drums will hoist two tanks of 2,400 gal. per minute. This gives an output of 7,000,000 gal. per 24 hours. By slightly increasing the speed of the engine this amount can be increased 10%, which is 25% in excess of the calculated maximum demand on the shaft. The cages in the cage compartments are so arranged that they can be disconnected, and water buckets substituted for them. This would be a total output of over 14,000,000 gal. per 24 hours at the normal speed of the engine. One great advantage of this style of pumping plant is that there is absolutely no fear of drowning the pumps.

Some years ago the Hamilton iron mine, in Michigan, was drowned by a sudden inrush of water that drove the pumpmen from the pumps. In order to remove this large volume of water, special bailing buckets were substituted for the ordinary mine skips. These bailing buckets ran on the inclined skip road, and unwatered the mine in a remarkably short time.

Sinking Pumps.—Sinking pumps may be either single or duplex in their action, and may be inside or outside packed. Outside-packed single-acting pumps are in many ways preferable, owing to the fact that they are less liable to get out of order. One requisite of any sinking pump is that it should have as few exposed parts as possible, and that these parts should be so placed that they will be protected from injury by blasting to as great an extent as possible. Sinking pumps are usually provided with a telescopic section in the suction pipe, and sometimes also in the discharge pipe, so that they can be moved down several feet without having to break the joints of the piping.

Pumps for Acid Waters.—Where mine waters are acid in their nature, brass or brass-lined pumps are usually employed, and in some cases even wooden pumps have been used, as, for instance, in the Swedish copper mines, though this practice is disappearing in favor of the use of brass or copper linings. The pipes for such pumps should be of brass or copper tubing, or should be lined with some substance that will not be affected by the acid of the water. Sometimes wooden linings are employed, placed as shown in Figs. 21 and 22, Fig. 21 being a section of the pipe with the lining complete, and Fig. 22 a cross-section of one of the individual boards used in the lining. These are usually made of pine about $\frac{3}{8}$ in. thick, and are grooved on each end as shown. They are sprung in so as to complete a circle on the inside of the pipe, and then long, thin, wooden keys driven into the grooves. When the water is allowed to go into the pipes, the linings swell and make all joints perfectly tight. Elbows and other crooked sections are lined with sheet lead beaten in with a mallet.

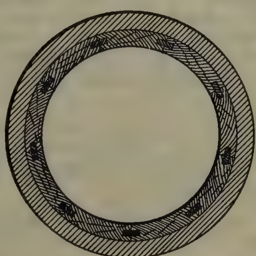


FIG. 21.

FIG. 22.

FUELS.

The value of any fuel is measured by the number of heat units that its combustion will generate, a unit of heat being the amount required to heat 1 lb. of water 1° F. The fuels used in generating steam are composed mainly of carbon and hydrogen, ash, and moisture, with sometimes small quantities of other substances not materially affecting their value.

Combustible is that portion which will burn; the ash or residue varies from 2% to 36% in different fuels.

The following table gives, for the more common combustibles, the air required for complete combustion, the temperature with different proportions of air, the theoretical value, and the highest attainable value under a steam boiler, assuming that the gases pass off at 320°, the temperature of steam at 75 lb. pressure, and the incoming draft to be at 60°; also, that with chimney draft twice and with blast only the theoretical amount of air is required for combustion.

TABLE OF COMBUSTIBLES.

Kind of Combustible.	Air Required.	Temperature of Combustion.				Theoretical Value.		Highest Attainable Value Under Boiler.	
	Pounds per Pound of Combustible.	With Theoretical Supply of Air.	With $1\frac{1}{2}$ Times Theoretical Supply of Air.	With Twice Theoretical Supply of Air.	With Three Times Theoretical Supply of Air.	Pounds of Water Raised 1° per Pound of Combustible.	Lb. of Water Evaporated From and at 212°, with 1 Lb. Combustible.	With Chimney Draft.	With Blast, Theoretical Supply of Air at 60°, Gas 320°.
Hydrogen	36.00	5,750	3,860	2,860	1,940	62,032	64.20		
Petroleum	15.43	5,050	3,515	2,710	1,850	21,000	21.74	18.55	19.90
Carbon { Charcoal, Coke, Anthracite }	12.13	4,580	3,215	2,440	1,650	14,500	15.00	13.30	14.14
Coal, Cumberland,	12.06	4,900	3,360	2,550	1,730	15,370	15.90	14.28	15.06
Coal, Coking bituminous	11.73	5,140	3,520	2,680	1,810	15,837	16.00	14.45	15.19
Coal, Cannel	11.80	4,850	3,330	2,540	1,720	15,080	15.60	14.01	14.76
Coal, Lignite	9.30	4,600	3,210	2,490	1,670	11,745	12.15	10.78	11.46
Peat, Kiln dried	7.68	4,470	3,140	2,420	1,660	9,660	10.00	8.92	9.42
Peat, Air dried, 25% water	5.76	4,000	2,820	2,240	1,550	7,000	7.25	6.41	6.78
Wood, Kiln dried	6.00	4,080	2,910	2,260	1,530	7,245	7.50	6.64	7.02
Wood, Air dried, 20% water	4.80	3,700	2,607	2,100	1,490	5,600	5.80	4.08	4.39

The effective value of all kinds of wood *per pound*, when dry, is substantially the same. This is usually estimated at .4, the value of the same weight of coal. The following are the weights and comparative values of different woods by the cord:

Wood.	Weight.	Wood.	Weight.
Hickory (shell bark)	4,469	Beech	3,126
Hickory (red heart)	3,705	Hard maple	2,878
White oak	3,821	Southern pine	3,375
Red oak	3,254	Virginia pine	2,680
Spruce	2,325	Yellow pine	1,904
New Jersey pine	2,137	White pine	1,868

Much is said nowadays about the wonderful saving that is to be expected from the use of petroleum for fuel. This is all a myth, and a moment's attention to facts is sufficient to convince any one that no such possibility exists. Petroleum has a heating capacity, when fully burned, equal to from 21,000 to 22,000 B. T. U. per lb., or, say, 50% more than coal. But, owing to the ability to burn it with less losses, it has been found, through extended experiments by the pipe lines, that under the same boilers, and doing the same work, 1 lb. of petroleum is equal to 1.8 lb. of coal. The experiments on locomotives in Russia have shown practically the same value, or 1.77. Now, a gallon of petroleum weighs 6.7 lb. (though the standard buying and selling weight is 6.5 lb.), and therefore an actual gallon of petroleum is equivalent under a boiler to 12 lb. of coal, and 190 standard gallons are equal to a gross ton of coal. It is very easy with these data to determine the relative cost. At the wells, if the oil is worth, say, 2 cents a gallon, the cost is equivalent to \$3.80 per ton for coal at the same place, while at, say, 3 cents per gallon, the lowest price at which it can be delivered in the vicinity of New York, it costs the same as coal at \$5.70 per ton. The Standard Oil Company estimates that 173 gal. are equal to a gross ton of coal, allowing for incidental savings, as in grate bars, carting ashes, attendance, etc.

Sawdust can be utilized for fuel to good advantage by a special furnace and automatic feeding devices. Spent tan bark is also used, mixed with some coal, or it may be burned without the coal in a proper furnace. Its value is about one-fourth that of the same weight of wood as it comes from the press, but, when dried, its value is about 85% of the same weight of wood in same state of dryness.

It has been estimated that, on an average, 1 lb. of coal is equal, for steam-making purposes, to 2 lb. dry peat, $2\frac{1}{4}$ to $2\frac{1}{2}$ lb. dry wood, $2\frac{1}{2}$ to 3 lb. dried tan bark, $2\frac{3}{4}$ to 3 lb. cotton stalks, $3\frac{1}{4}$ to $3\frac{3}{4}$ lb. wheat or barley straw, and 6 to 8 lb. wet tan bark.

Natural gas varies in quality, but it is usually worth 2 to $2\frac{1}{2}$ times the same weight of coal, or about 30,000 cu. ft. are equal to a ton of coal.

Slack, or the screenings from coal, when properly mixed—anthracite and bituminous—and burned by means of a blower on a grate adapted to it, is nearly equal in combustible value to coal, but its percentage of refuse is greater.

The accompanying table of proximate analyses and heating values of American coals was compiled by Mr. William Kent, for the 1898 edition of the Babcock & Wilcox Co.'s book, "Steam." The analyses are selected from various sources, and, in general, are averages of many samples. The heating values per pound of combustible are either obtained from direct calorimetric determinations or calculated from ultimate analyses, except those marked (?), which are estimated from the heating values of coals of similar composition. The figures in the last column are obtained by dividing the figures in the preceding column by 965.7, the number of heat units required to evaporate 1 lb. of water at 212° into steam of the same temperature.

The heating values per pound of combustible given in the table, except those marked (?), are probably within 3% of the average actual heating values of the combustible portion of the coals of the several districts. When the percentage of moisture and ash in any given lot of coal is known, the heating value per pound of coal may be found, approximately, by multiplying the heating value per pound of combustible of the average coal of the district by the difference between 100% and the sum of the percentages of moisture and ash.

The heating effect is calculated on the basis of the coal burned to carbon dioxide and liquid water at 100° C., and is stated either in calories per kilogram or English heat units per pound. The theoretical evaporative effect is calculated by dividing the number of calories per kilogram by 536, or the number of English heat units per pound by 965. In either case, it expresses the theoretical number of kilograms or pounds of water converted into steam from and at 100° C., by 1 kilogram or 1 lb. of coal.

A committee of the Western Society of Engineers, of Pittsburg, report that 1 lb. of good coal = $7\frac{1}{2}$ cu. ft. of natural gas. When burned with just enough air, its temperature of combustion is 4,200° F. The Westinghouse Air Brake Co. found from experiment that 1 lb. Youghiogheny coal = $12\frac{1}{4}$ cu. ft. natural gas, or 1,000 cu. ft. natural gas = 81.6 lb. coal. Indiana natural gas gives 1,000,000 B. T. U. for 1,000 cu. ft. and weighs .045 lb. per cu. ft.

PROXIMATE ANALYSES AND HEATING VALUES OF AMERICAN COALS.

Coal.	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Heating Value per Lb. Coal, B. T. U.	Volatile Matter Per Cent. of Combustible.	Fixed Carbon. Per Cent. of Combustible.	Heating Value per Lb. Combustible.	Theoretical Evaporation From and at 212° per Lb. Combustible.
Anthracite.										
Northern Coal Field	3.42	4.38	83.27	8.20	.73	13,160	5.00	95.00	14,900	15.42
East Middle Coal Field	3.71	3.08	86.40	6.22	.58	13,420	3.44	96.56	14,900	15.42
West Middle Coal Field	3.16	3.72	81.59	10.65	.50	12,840	4.36	95.64	14,900	15.42
Southern Coal Field	3.09	4.28	83.81	8.18	.64	13,220	4.85	95.15	14,900	15.42
Semianthracite.										
Loyalsock Field	1.30	8.10	83.34	6.23	1.63	13,920	8.86	91.14	15,500	16.05
Bernice Basin	.65	9.40	83.69	5.34	.91	13,700	10.98	89.02	15,500	16.05
Semibituminous.										
Broad Top, Pa.	.79	15.61	77.30	5.40	.90	14,820	17.60	82.40	15,800	16.36
Clearfield Co., Pa.	.76	22.52	71.82	3.99	.91	14,950	24.60	75.40	15,700	16.25
Cambria Co., Pa.	.94	19.20	71.12	7.04	1.70	14,450	22.71	77.29	15,700	16.25
Somerset Co., Pa.	1.58	16.42	71.51	8.62	1.87	14,200	20.37	79.63	15,800	16.36
Cumberland, Md.	1.09	17.30	73.12	7.75	.74	14,400	19.79	80.21	15,800	16.36
Pocahontas, Va.	1.00	21.00	74.39	3.03	.58	15,070	22.50	77.50	15,700	16.25
New River, W. Va.	.85	17.88	77.64	3.36	.27	15,220	18.95	81.05	15,800	16.36
Bituminous.										
Connellsville, Pa.	1.26	30.12	59.61	8.23	.78	14,050	34.03	65.97	15,300	15.84
Youghiogheny, Pa.	1.03	36.50	59.05	2.61	.81	14,450	38.73	61.27	15,000	15.53
Pittsburg, Pa.	1.37	35.90	52.21	8.02	1.80	13,410	41.61	58.39	14,800	15.32
Jefferson Co., Pa.	1.21	32.53	60.99	4.27	1.00	14,370	35.47	64.53	15,200	15.74
Middle Kittaning Seam, Pa.	1.81	35.33	53.70	7.18	1.98	13,200	40.27	59.73	14,500	15.01
Upper Freeport Seam, Pa. and Ohio	1.93	35.90	50.19	9.10	2.89	13,170	43.59	56.41	14,800	15.32
Thacker, W. Va.	1.38	35.04	56.03	6.27	1.28	14,040	39.33	60.67	15,200	15.74
Jackson Co., Ohio	3.83	32.07	57.60	6.50		13,090	35.76	64.24	14,600	15.11
Brier Hill, Ohio	4.80	34.60	56.30	4.30		13,010	38.20	61.80	14,300	14.80
Hocking Valley, Ohio	6.59	34.97	48.85	8.00	1.59	12,130	42.81	57.19	14,200	14.70
Vanderpool, Ky.	4.00	34.10	54.60	7.30		12,770	38.50	61.50	14,400	14.91
Muhlenberg Co., Ky.	4.33	33.65	55.50	4.95	1.57	13,060	38.86	61.14	14,400(?)	14.91
Scott Co., Tenn.	1.26	35.76	53.14	8.02	1.80	13,700	34.17	65.83	15,100(?)	15.63
Jefferson Co., Ala.	1.55	34.44	59.77	2.62	1.42	13,770	37.63	62.37	14,400(?)	14.91
Big Muddy, Ill.	7.50	30.70	53.80	8.00		12,420	36.30	63.70	14,700	15.22
Mt. Olive, Ill.	11.00	35.65	37.10	13.00		10,490	47.00	53.00	13,800	14.29
Streator, Ill.	12.00	33.30	40.70	14.00		10,580	45.00	55.00	14,300	14.80
Missouri	6.44	37.57	47.94	8.05		12,230	43.94	56.06	14,300(?)	14.80
Lignite and Lignitic Coals.										
Iowa	8.45	37.09	35.60	18.86		8,720	51.03	48.97	12,000(?)	12.42
Wyoming	8.19	38.72	41.83	11.26		10,390	48.07	51.93	12,900(?)	13.35
Utah	9.29	41.97	44.37	3.20	1.18	11,030	48.60	51.40	12,600(?)	13.04
Oregon lignite	15.25	42.98	33.32	7.11	1.66	8,540	54.95	45.05	11,000(?)	11.39

A **British thermal unit** (B. T. U.) is the quantity of heat required to raise the temperature of 1 lb. of water 1° F. at or near the temperature of maximum density, 39.1° F.

A **calorie** is the quantity of heat required to raise the temperature of 1 kilogram of water 1° C. at or about 4° C.

A **pound calorie** is the quantity of heat necessary to raise the temperature of 1 lb. of water 1° C.

1 French calorie = 3.968 British thermal units.
1 B. T. U. = .252 calorie.
1 lb. calorie = $\frac{9}{5}$ B. T. U. = .4536 calorie.

The heating value of any coal may be calculated from its ultimate analysis, with a probable error not exceeding 2%, by Dulong's formula:

$$\text{Heating value per lb.} = 146\,C + 620\left(H - \frac{O}{8}\right),$$

in which C, H, and O are, respectively, the percentages of carbon, hydrogen, and oxygen.

$$\text{Heat in pound calorie} = 8{,}080\,C + 34{,}462\left(H - \frac{O}{8}\right),$$

$$\text{or} = 8{,}080\,C + 34{,}462\left(H - \frac{O}{8}\right) + 2{,}250\,S.$$

$$\text{Heat in B. T. U.} = 14{,}650\,C + 62{,}100\left(H - \frac{O}{8}\right),$$

in which C, O, H, and S represent the weights of carbon, oxygen, hydrogen, and sulphur in 1 lb. of the substance.

COMPOSITION OF FUELS.

(*Mechanical Draft, B. F. Sturtevant Co.*)

Description.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
Anthracite.						
France	90.9	1.47	1.53	1.00	.80	4.3
Wales	91.7	3.78	1.30	1.00	.72	1.5
Rhode Island	85.0	3.71	2.39	1.00	.90	7.0
Pennsylvania	78.6	2.50	1.70	.80	.40	14.8
Semibituminous.						
Maryland	80.0	5.00	2.70	1.10	1.20	8.3
Wales	88.3	4.70	.60	1.40	1.80	3.2
Bituminous.						
Pennsylvania	75.5	4.93	12.35	1.12	1.10	5.0
Indiana	69.7	5.10	19.17	1.23	1.30	3.5
Illinois	61.4	4.87	35.42	1.41	1.20	5.7
Virginia	57.0	4.96	26.44	1.70	1.50	8.4
Alabama	53.2	4.81	32.37	1.62	1.30	6.7
Kentucky	49.1	4.95	41.13	1.70	1.40	7.2
Cape Breton	67.2	4.26	20.16	1.07	1.21	6.1
Vancouver Island	66.9	5.32	8.76	1.02	2.20	15.8
Lancashire gas coal	80.1	5.50	8.10	2.10	1.50	2.7
Boghead cannel	63.1	8.90	7.00	.20	1.00	19.8
Lignite.						
California brown	49.7	3.78	30.19	1.00	1.53	13.8
Australian brown	73.2	4.71	12.35	1.11	.63	8.0
Petroleum.						
Pennsylvania (crude)	84.9	13.70	1.40			
Caucasian (light)	86.3	13.60	.10			
Caucasian (heavy)	86.6	12.30	1.10			
Refuse	87.1	11.70	1.20			

CLASSIFICATION, COMPOSITION, AND PROPERTIES OF COALS.

Coals may be broadly divided into two classes: Anthracite, or hard, coal; and bituminous, or soft, coal.

Anthracite, or Hard, Coal.—Specific gravity, 1.30 to 1.70. This is the densest, hardest, and most lustrous of all varieties. It burns with little flame and no smoke, but gives a great heat. Contains very little volatile combustible matter. Color, deep black, shining; sometimes iridescent. Fracture, conchoidal.

Semianthracite coal is not so dense nor so hard as the true anthracite. Its percentage of volatile combustible matter is somewhat greater, and it ignites more readily.

Bituminous, or Soft, Coal.—Specific gravity, 1.25 to 1.40. It is generally brittle; has a bright pitchy or greasy luster, and is rather fragile as compared with anthracite. It burns with a yellow smoky flame, and gives, on distillation, hydrocarbon oils or tar.

Under the term "bituminous" are included a number of varieties of coal that differ materially under the action of heat, giving rise to the general classification: Coking or caking coals, and free-burning coals.

Semibituminous coal has the same general characteristics as the bituminous, although it is usually not so hard, and its fracture is more cuboidal. The

percentage of volatile combustible matter is less. It kindles readily, and burns quickly with a steady fire, and is much valued as a steam coal.

Coking coals are those that become pasty or semiviscid in the fire; and, when heated in a close vessel, become partially fused and agglomerate into a mass of coherent coke. This property of coking may, however, become greatly impaired, if, indeed, not entirely destroyed, by weathering.

Free-burning coals have the same general characteristics as the coking coals, but they burn freely without softening, and do not fuse or cake together in any sensible degree.

Splint coal has a dull black color, and is much harder and less frangible than the coking coal. It is readily fissile, like slate, but breaks with difficulty on cross-fracture. It ignites less readily, but makes a hot fire, constituting a good house coal.

WEIGHTS AND MEASUREMENTS OF COAL.

(*Coxe Bros. & Co., Chicago, Ill.*)

Coal.	Weight per Cubic Foot. Pounds.	Cubic Feet per Ton, 2,000 Lb.	Coal.	Weight per Cubic Foot. Pounds.	Cubic Feet per Ton, 2,000 Lb.
Lehigh lump	55.26	36.19	Free-burning egg	56.07	35.67
Lehigh cupola	55.52	36.02	Free-burning stove	56.33	35.50
Lehigh broken	56.85	35.18	Free-burning nut	56.88	35.16
Lehigh egg	57.74	34.63	Pittsburg	46.48	43.03
Lehigh stove	58.15	34.39	Illinois	47.22	42.35
Lehigh nut	58.26	34.32	Connellsville coke	26.30	76.04
Lehigh pea	53.18	37.60	Hocking	49.30	40.56
Lehigh buckwheat	54.04	37.01	Indiana block	43.85	45.61
Lehigh dust	57.25	34.93	Erie	48.07	41.61
			Ohio cannel	49.18	40.66

Cannel coal differs from the ordinary bituminous coal in its texture. It is compact, with little or no luster and without any appearance of a banded structure. It breaks with a smooth conchoidal fracture, kindles readily, and burns with a dense smoky flame. It is rich in volatile matter, and makes an excellent gas coal. Color, dull black and grayish black.

Lignite, or brown coal, often has a lamellar or woody structure; is sometimes pitch black, but more often rather dull and brownish black. It kindles readily and burns rather freely with a yellow flame and comparatively little smoke, but it gives only a moderate heat. It is generally non-coking. The percentage of moisture present is invariably high—from 10% to 30%.

The subdivisions given above are entirely arbitrary, as the different varieties of coal are found to shade insensibly into one another. The following are two classifications according to percentages of volatile combustible matter:

CLASSIFICATION OF COAL ACCORDING TO VOLATILE COMBUSTIBLE.

Coal.	Per Cent.	*Kent.* Per Cent.
Anthracite	2.5 to 6	0 to 7
Semianthracite	7 to 10	7.5 to 12
Semibituminous	12 to 20	12.5 to 25
Bituminous	over 20	25 to 50
Lignite		over 50

The Composition of Coals.—A proximate analysis determines the proportion of those products of a coal having the most important bearing on its uses. These substances as usually presented are: Moisture, or water, volatile com-

bustible matter, fixed carbon, sulphur, and ash. In addition to these, the following physical properties are generally given: Color of ash, specific gravity, and strength or hardness. The determination of these eight factors gives a fair general idea of the adaptabilities of a coal.

Moisture, or water, in coal, has no fuel value, is an inert constituent, dug, handled, and hauled, and finally expelled at a cost of fuel. Each per cent. of moisture means 20 lb. less fuel for each ton of coal.

Volatile combustible matter is an important constituent of coal, the amount and quality deciding whether a coal is suitable for the manufacture of illuminating gas. The coking of coal also is largely dependent on this constituent. When a large percentage of volatile combustible matter is present, coals ignite easily and burn with a long yellow flame, and, in ordinary combustion, give out dense smoke, and form soot. This quality makes a fuel objectionable for railway and sometimes for naval use.

The **fixed carbon** is the principal combustible constituent in coal, and, in bituminous and semibituminous coals, the steaming value is in proportion to the percentage of fixed carbon. Though the fixed carbon of a coal evaporates much less water than an equivalent weight of the volatile combustible matter when properly burnt, in practice, so much of the latter is lost through careless firing, or improper furnace construction, that the relative steaming value of a coal may be fairly approximated by assuming the carbon to be the only useful constituent.

Sulphur will burn and develop heat, and is not inert like moisture and ash. But it corrodes grates and boilers; in the blast furnace it injures iron, and produces a hot short pig, and is objectionable in coal for forge use. In gas making, the sulphur must be removed. It usually occurs in coal in the form of iron pyrites, which, oxidizing, causes disintegration, and sometimes spontaneous combustion. It is then an element of danger and loss.

Ash is an inert constituent, which means 20 lb. of weight to be handled and 20 lb. loss per ton of coal for each per cent. present. Water in coal is removed at the cost of fuel, while ashes are removed at extra cost of labor. It is estimated that if the cost of stoking coal is $6\frac{2}{3}\%$ of the cost of coal (coal at $3.00 per ton, and labor at $1.00 per day), and with cost of handling ashes double that of stoking coal, 5% of ash will lessen the fuel value of coal over 6%; 10% ash, over 12%; and so on.

The **color of the ash** furnishes a rough estimate of the amount of iron contained in a fuel. Iron in an ash makes it more fusible, and increases its tendency to clinker. In domestic consumption, where the temperature is low, the quantity of ash is of more importance than its fusibility, but for steam purposes, where an excessive heat is required, ashes of a clinkering coal will fuse into a vitreous mass and accumulate upon the grate bars and exclude the passage of necessary air. The practicability of employing a coal will often be determined by the quality of the clinkering of the ashes. Under such conditions, such coals are best whose ashes are nearly pure white and which contain little or no alkali nor any lime, and do not contain silica and alumina.

The **specific gravity** is an important factor when there is restriction of space, as on railway cars and in ship bunkers. A given bulk of anthracite coal will weigh from 10% to 15% more than the same bulk of bituminous coal, so that from 10% to 15% more pounds of fuel can be carried in the same place. The average specific gravity of anthracite coal is 1.5, and a cubic yard weighs about 2,531 lb.

The average specific gravity of American bituminous coals, and of grades intermediate between them and anthracite, is about 1.325, and 1 cu. yd. weighs about 2,236 lb.

Strength or hardness is valuable in preventing waste. In soft coal, much is ground to dust in mining and at the tipple. In railway transportation, soft coal is crushed, which further increases the loss, and the coal reaches market in bad condition. A very soft coal is shipped in lump, and is not in so wide demand. For marine use, a soft coal is objectionable, because of disintegration by the motion of the ship. Strength is a requisite for the use of raw coal in the blast furnace, and also to prevent excessive loss of coal through the grates in ordinary furnaces.

Steaming Coals.—For steam making, the superiority of coals high in combustible constituents is admitted, and those with the higher percentage of fixed carbon are the most desirable. But the consideration of the steaming qualities of a coal involves, also, a consideration of the form of furnace and of all the conditions of combustion. The evaporative power of a coal in

practice cannot be stated without reference to the conditions of combustion, and every practical test of a coal, to be thorough, should lead to a determination of the best form of furnace for that coal, and should furnish knowledge as to what class of furnaces in actual use such coal is specially adapted. It is not sufficient that in comparative tests of coals the same conditions should exist with each, but there should also be determined the best conditions for each coal.

Of coals high in fixed carbon, the semianthracites and the semibituminous rank as high as the anthracites in meeting the various requirements of a quick and efficient steaming coal.

For railway use, these coals have been found to excel anthracites in evaporating power. The comparative absence, in semibituminous coals, of smoke, which means loss of combustible matter as well as discomfort to the traveler, is sufficient to suggest the superiority of these coals over bituminous coals for such use. In fact, the high rate of combustion and the strong draft necessary in locomotives is particularly unfavorable to the economic combustion of bituminous coal. Such semibituminous coals are also specially well suited for small tubular boilers, firebox steam boilers, or other forms with small unlined combustion chambers, in which the gases from bituminous coals become cooled, are not burnt, and deposit soot in the tubes.

Steaming coal should kindle readily and burn quickly but steadily, and should contain only enough volatile matter to insure rapid combustion. It should be low in ash and sulphur, should not clinker, and when it is to be transported should not easily crumble and break.

Coals for Iron Making.—For the manufacture of iron and for metallurgical purposes, coal is chiefly used after being converted into coke, though it is also used to a limited extent in the raw state. Coal directly used must be strong and not swell nor disintegrate so as to choke the furnace. It should be capable of producing a high heat and should not contain a large amount of sulphur or phosphorus.

Coke.—Coke is the fixed carbon of a coal, a fused and porous product produced by the distillation of the gaseous constituent. For metallurgical use, it should be firm, tough, and bright, with a sonorous ring, and should contain not over 1% of sulphur. For blast-furnace use, a dense coke is objectionable, and the best is the one with the largest cell structure and the hardest cell wall. A high percentage of volatile hydrocarbon is, as a rule, necessary for a good coking coal.

The fusibility of the carbon, the amount of disposable hydrogen, the tenacity with which the gaseous constituents are held, all affect the results in coking. Further, coal that is mined near the outcrop, and has been subjected to the influence of the weather, loses its capacity for coking. The process of manufacture should, however, be adapted to the character of the coal, as it has an important, though secondary, influence on the physical character, uniformity of quality, and dryness of a coke. Coals of inferior grade are made to produce good coke by using coke ovens in which the heat of the gases is applied externally to the coke chamber, but the coal is generally first carefully crushed and washed. Further, the depth of the charge and length of heating have an important bearing.

As at present understood, and in the present mode of manufacture, the essential qualities of a good coking coal are: that it shall contain not less than 20% nor more than 30% of volatile hydrocarbons, and not too much ash; that on being heated it must pass through a thoroughly fused or pasty condition; and that when in this condition, it must part with its volatile matter in such a manner as to form innumerable small pores.

If a coal contains less than 20% of volatile matter, it will not fuse properly, while if it has more than 30% the porous structure will be unduly developed at the expense of the strength of the pore walls; on the other hand, many coals lying between these limits will not fuse at all, and therefore do not coke, while others fuse properly but give off their gas so as to form large and thin-walled pores.

Ordinary analyses do not indicate whether or not a coal is a good coking coal, and they indicate simply by giving the amount of carbon, ash, and sulphur, what will be the probable purity of the coke formed. The coal of the Pittsburg bed in the Connellsville basin of Pennsylvania is considered by many as the standard coking coal, but coals whose analysis differ very materially from that of Connellsville undoubtedly give most excellent cokes, which are equal to or very nearly equal to, that from Connellsville, as, for instance, the Pocahontas coke, Virginia.

Domestic Coals.—In domestic use, coal is burned in open grates, in closed stoves with ordinary fire bowls and flat grates, or with basket grates in small furnaces for hot-air heating, and in cooking stoves. In all these, the coal that sustains a mild, steady combustion, and remains ignited at a low temperature with a comparatively feeble draft, is the best. A coal burning with a smoky flame is objectionable as producing much soot and dirt, especially for open grates or cooking purposes. For self-feeding stoves, or for base burners, a dry non-coking coal is necessary. A very free and fiercely burning coal is not desirable, particularly in stoves, as the temperature cannot be easily regulated. A sulphurous coal is also bad, as it produces stifling gases with a defective draft, and corrodes the grates and fire bowls. The difficulty from clinkering is not so great in domestic uses, as the temperature is not generally high enough to fuse the ash. A stony, hard ash that will not pass between the grate bars is bad, and light pulverulent ash is best.

Gas Coals.—Mr. H. C. Adams, of The American Gas Light Association, says: "The essentials of a good gas coal are a low percentage of ash, say 5%, and of sulphur, say ½ of 1%, a generous share, say 37% to 40% of volatile matter, charged with rich illuminating hydrocarbons. And it should yield, under present retort practice, 85 candle-feet to the pound carbonized. It should be sufficiently dense to bear transportation well, so that, when carried long distances, it may not arrive at its destination largely reduced to slack or fine coal of the consistency of sand. And it should possess coking qualities that will bring from the retorts, after carbonization, about 60% of clean, strong, bright coke."

Blacksmith Coals.—A good coal for blacksmith purposes should have a high heating power, should contain a very small amount of sulphur, if any, should coke sufficiently to form an arch on the forge, and should also be low in ash.

From the above, it is readily seen that the analysis of a coal does not necessarily determine its value or the uses to which it can be put. However, by examining the analyses given in the table on page 168, certain standards may be adopted as showing in a general way about what the analysis of coal should be for certain purposes. For steam purposes, the semibituminous coals have established reputations. For gas coals, that from Youghiogheny, Pa., is well known. For blacksmiths, Broad Top and Tioga County, Pennsylvania, coals are standards; while for coking, Connellsville is recognized as a standard.

The sizes of anthracite coal vary. The sizes of screen mesh and bar openings used for separating, range as follows:

Lump, over bars placed 7 to 9 in. apart.
Steamboat, over bars placed 3½ to 5 in. apart and through bars 7 in. apart.
Grate, over 2¾ in. and through 4½ in. square mesh.
Egg, over 2 in. and through 2¾ in. square mesh.
Stove, over 1⅜ in. and through 2 in. square mesh.
Chestnut, over ¾ in. and through 1⅜ in. square mesh.
Pea, over ½ in. and through ¾ in. square mesh.
Buckwheat, over ¼ in. and through ½ in. square mesh.
No. 2 Buckwheat, or Bird's-eye, over ¼ in. and through $\frac{5}{16}$ in. square mesh.

The sizes of bituminous coal are Lump, Nut, and Slack.

All coal that passes over bars 1¼ in. apart is called *Lump*.

All coal that passes through bars 1¼ in. apart and over bars ¾ in. apart is called *Nut*.

All coal that passes through bars ¾ in. apart is called *Slack*.

ANALYSIS OF COAL.

The following is the outline of the method recommended for the analysis of coal by a committee of the American Chemical Society, Messrs. W. F. Hillebrand, C. B. Dudley, and W. A. Noyes:

Sampling.—At least 5 lb. of coal should be taken for the original sample, with care to secure pieces that represent the average. These should be broken up and quartered down to obtain the smaller sample, which is to be reduced to a fine powder for analysis. The quartering and grinding should be carried out as rapidly as possible, and immediately after the original sample is taken, to prevent gain or loss of moisture. The powdered coal should be kept in a tightly stoppered tube, or bottle, until analyzed. Unless the coal contains less than 2% of moisture, the shipment of large samples in wooden boxes should be avoided.

In *boiler tests*, shovelfuls of coal should be taken at regular intervals and put in a tight covered barrel, or some air-tight covered receptacle, and the latter should be placed where it is protected from the heat of the furnace.

In *sampling from a mine*, the map of the mine should be carefully examined and points for sampling located in such a manner as to fairly represent the body of the coal. These points should be placed close to the working face. Before sampling, make a fresh cut of the face from top to bottom to a depth that will insure the absence of possible changes or of sulphur and smoke from the blasting powders. Clean the floor and spread a piece of canvas to catch the cuttings. Then, with a chisel, make a cutting from floor to roof, say 3 in. wide and about 1 in. deep. Do not chisel out the shale or other impurities that it is the practice at that mine to reject. Measure the length of the cutting made, but do not include the impurities in this measurement. With a piece of flat iron and a hammer, break all pieces to quarter-inch cubes or less, without removing from the cloth. Quarter down and transfer to a sealed bottle or jar. For the "run-of-mine" sample, samples taken at several points in this manner should be mixed and quartered down. If the vein varies in thickness at different points, the samples taken at each point should correspond in amount to the thickness of the vein. For instance, a small measure may be filled as many times with the coal of the sample as the vein is feet in thickness. Should there appear differences in the nature of the coal, it will be more satisfactory to take, in addition to the general sample, samples of such portions of the vein as may display these differences.

Moisture.—Dry 1 g. of the coal in an open porcelain or platinum crucible at 104° to 107° C. for 1 hour, best in a double-walled bath containing pure toluene. Cool in a desiccator and weigh covered.

Volatile Combustible Matter.—Place 1 g. of fresh, undried coal in a platinum crucible, weighing 20 to 30 g., and having a tightly fitting cover. Heat over the full flame of a Bunsen burner for 7 minutes. The crucible should be supported on a platinum triangle with the bottom 6 to 8 cm. above the top of the burner. The flame used should be fully 20 cm. high when burning free, and the determination made in a place free from drafts. The upper surface of the cover should burn clear, but the under surface should remain covered with carbon. To find "volatile combustible matter," subtract the percentage of moisture from the loss found here.

Ash.—Burn the portion of coal used for the determination of moisture at first over a very low flame, with the crucible open and inclined, until free from carbon. If properly treated, this sample can be burned much more quickly than the dense carbon left from the determination of volatile matter.

Fixed Carbon.—This is found by subtracting the percentage of ash from the percentage of coke.

Sulphur (Eschka's Method).—Mix thoroughly 1 g. of the finely powdered coal with 1 g. of magnesium oxide and ½ g. of dry sodium carbonate, in a thin 75 to 100 c. c. platinum dish or crucible. The magnesium oxide should be light and porous, not a compact, heavy variety. The dish is heated on a triangle over an alcohol lamp, held in the hand at first. Gas must not be used, because of the sulphur it contains. The mixture is frequently stirred with a platinum wire and the heat raised very slowly, especially with soft coals. The flame is kept in motion and barely touching the dish, at first, until strong glowing has ceased, and is then increased gradually until, in 15 minutes, the bottom of the dish is at a low red heat. When the carbon is burned, transfer the mass to a beaker and rinse the dish, using about 50 c. c. of water. Add 15 c. c. of saturated bromine water and boil for 5 minutes. Allow to settle, decant through a filter, boil a second and third time with 30 c. c. of water, and wash until the filtrate gives only a slight opalescence with silver nitrate and nitric acid. The volume of the filtrate should be about 200 c. c. Add 1½ c. c. of concentrated hydrochloric acid, or a corresponding amount of dilute acid (8 c. c. of an acid of 8%). Boil until the bromine is expelled, and add to the hot solution, drop by drop, especially at first, and with constant stirring, 10 c. c. of a 10% solution of barium chloride. Digest on the water bath, or over a low flame, with occasional stirring until the precipitate settles clear quickly. Filter and wash, using either a Gooch crucible or a paper filter. The latter may be ignited moist in a platinum crucible, using a low flame until the carbon is burned.

In the case of coals containing much pyrites or calcium sulphate, the

residue of magnesium oxide should be dissolved in hydrochloric acid and the solution tested for sulphuric acid.

When the sulphur in the coal is in the form of pyrites, that compound is converted almost entirely into ferric oxide in the determination of ash, and, since 3 atoms of oxygen replace 4 atoms of sulphur, the weight of the ash is less than the weight of the mineral matter in the coal by $\frac{5}{8}$ the weight of the sulphur. While the error from this source is sometimes considerable, a correction for "proximate" analyses is not recommended. When analyses are to be used as a basis for calculating the heating effect of the coal, a correction should be made.

The analysis of a coal may be reported in three different forms, as percentages of the moist coal, of the dry coal, or of the combustible. Thus, suppose 1 g. of coal is analyzed, and the first heating shows a loss of weight of .1 g., the second of .3 g., the third .5 g., the remainder, or ash, weighing .1 g., the complete report would be as follows:

	Per Cent. of the Moist Coal.	Per Cent. of the Dry Coal.	Per Cent. of the Combustible.
Moisture	10		
Volatile matter	30	33.33	37.50
Fixed carbon	50	55.56	62.50
Ash	10	11.11	
Total	100	100.00	100.00

STEAM.

A calculation of the power that coal possesses, compared with the useful work which steam engines exert, shows that probably in the very best engines not one-tenth of the power is converted into useful work, and in some very bad engines, probably not one one-hundredth. There are many causes for this; some we can never remedy, because to do so it would be necessary to exhaust the steam at a lower temperature than is practical. There are other causes that can and ought to be removed. We want good engines, good boilers, high-pressure steam, expansive working, and condensing appliances.

High-Pressure Steam.—Why should we use high-pressure steam? There are several good reasons. Whatever pressure we have available at the steam boiler, a certain amount is absorbed in overcoming the resistances of the engine and without doing any useful work. Suppose our available steam pressure is 20 lb., and 10 lb. are so absorbed; that leaves us only one-half; but, if we have 100 lb. available, it would leave us nine-tenths. High-pressure steam means fewer boilers and smaller engines, with foundations and houses of less dimensions. Then, again, the amount of work that it is possible to get out of a given quantity of steam depends on the difference between the temperature at the commencement of the stroke and the temperature at the end of the stroke.

Now, there is a limit as to how low the temperature can be at the end, and as we raise the commencing temperature, we enlarge the available difference. We may put the advantages of high-pressure steam in this way. By taking a fixed temperature in the condenser of, say, 100° F., and initial temperatures when the steam enters the cylinder, of varying amounts, the theoretic efficiency of that steam can be determined. Commencing with atmospheric pressure, we have an efficiency of 16.6%.

Lb.	Per Cent.	Lb.	Per Cent.
10	20.0	100	29.8
20	22.1	125	31.1
30	23.7	150	32.2
40	25.0	200	33.9
50	26.1	250	35.3
60	27.0	300	36.5
80	28.6		

We can only get in practice with steam a certain proportion of the theoretic power, and that proportion varies with the pressure of the steam.

In early days we used steam at atmospheric pressure, the efficiency being 16.6%; afterwards, we had, in compound engines of two cylinders, steam of 60 lb., the efficiency being 27%. Now we have triple-expansion engines, using steam at 150 lb., the efficiency being 32.2%. It will be observed that, although the efficiency increases as the steam pressure increases, the amount of that increase is a diminishing quantity, and it becomes so small at and beyond 150 lb. pressure that probably any gain in efficiency is not a satisfactory set-off to the additional expense of strengthening the parts of the engine. But then, how very few of our engines work nearly so high as 150 lb. pressure.

The advantages of high-pressure steam are not yet sufficiently appreciated. It is not merely the difference between 60 lb. and 120 lb. Suppose we use steam at 60 lb.; probably we shall get 50 lb. at engine, and resistances of engine will absorb 10 lb., leaving 40 lb. Now, suppose we use 120 lb., we can get at engine 110 lb., and if resistances of engine absorb 10 lb., we shall have 100 lb. as against 40 lb.

Expansion of Steam.—By "expansion of steam" we mean that at a certain point of the stroke we shut off steam supply from the boiler to the cylinder, and the steam already within the cylinder performs the remainder of the stroke unaided. Now, suppose we do not expand at all. Suppose we allow free admission of steam into the cylinder all through the stroke; we shall have at the end of the stroke pressure exactly similar to the pressure with which we commenced. Now, we cannot work a seam of coal and still have the coal left; we cannot get work out of steam and still have the work left in it, and so, if our steam pressure is the same at the end of the stroke as at the beginning, we simply discharge twice in each revolution a whole cylinder full of steam that has done no work at all, and waste it just the same as if we had discharged it from the boiler without passing through the engine at all. But some one will say, work has been done upon the engine while that steam was in the cylinder. True—and the explanation is, that while the steam is performing work its heat and pressure must diminish, and so long as the communication with the boiler is open, fresh heat comes from the boiler into the cylinder to take its place, and at the end of the stroke we have expended heat represented by the capacity of two cylinders, and have performed work as represented by the capacity of one cylinder. Now, suppose we close the communication, and beyond a certain point of the stroke allow no more steam to enter, we get an amount of work from the steam already in the cylinder, represented by the diminishing pressure of the steam by expansion.

Condensers.—The effective power of an engine does not depend on, and is not measured by, the pressure pushing the piston. There is always what is termed a *back pressure* holding the piston back, and the real effective pressure is evidently the difference between the two. Suppose we have a locomotive engine, or a winding engine, throwing exhaust into the open air. The back pressure cannot be less than the pressure of the open air, and, indeed, to overcome it, it must be something more. But if we can discharge our exhaust into some vessel from which atmospheric pressure and all other pressure has been removed, we know that atmospheric pressure amounts to about 15 lb., and the removal of that from the front of the piston is as good as adding 15 lb. behind.

BOILERS.

The steam boiler that will be the most suitable for a certain mine will depend on the nature of the feedwater, the cost of fuel, and the amount of steam required. When the acid water from the mine is used for feedwater, and fuel is cheap, the type of boiler generally used is either the plain cylindrical or flue boiler, because it is simple in construction and can therefore be easily cleaned and cheaply replaced when eaten by the mine water. The tubular or locomotive type is used where good water can be obtained, except in the best equipped plants, where the water-tube boiler is used. Feedwater taken from the mine, or containing acid, should be neutralized by lime or soda before being used. In case it contains minerals in solution, a feedwater separator should be employed to precipitate the mineral substance before the water is allowed to enter the boiler.

We always calculate the strength of a boiler in the direction of its diameter, because, theoretically, a boiler is twice as strong in the direction of length as direction of diameter. Many causes may bring about boiler explosions. First, bad materials; second, bad workmanship; third, bad water, which eats away the plates by internal corrosion; fourth, water lying upon plates, bringing about external corrosion; fifth, overpressure; sixth, safety valves sticking; seventh, water getting too low; eighth, excessive firing; ninth, hot gases acting on plates above water level; tenth, choking of feedpipes; eleventh, insufficient provision for expansion and contraction; twelfth, insufficient steam room and too sudden a withdrawal of a large quantity of steam; thirteenth, getting up steam, or knocking off a boiler too suddenly; fourteenth, allowing wet ashes to lie in contact with plates. The probable causes suggest their several remedies.

Wherever possible and except under certain circumstances, steam engines should not be placed in the mine, and certainly steam boilers should be in all cases placed upon the surface. Steam injures the ventilation, increasing the temperature where already too high, doing injury and causing inconvenience by condensation, and many fires in mines have been caused by underground boilers.

The Lancashire Boiler.—The colliery boiler that finds much favor in England is that class of Lancashire boiler which is 28 or 30 ft. long and 7 or 8 ft. in diameter, and has two large flues running through. There is no doubt that the marine type will generate more steam with a given amount of coal, and, consequently, is gaining ground, and will gain ground where coal is dear. But the Lancashire boiler is a good steam generator, and will not only work longer without repairs, but is less troublesome and expensive to repair. The favorite construction some few years ago was wrought iron with double-riveted horizontal joints and Galloway tubes (Galloway tubes are simply taper tubes running across the flues in the boiler), and expansion weldless hoops strengthening the flues and allowing for expansion and contraction. The dimensions were 7 ft. diameter, and from 28 to 30 ft. long, with internal flues each 2 ft. 9 in. diameter, the circular plates being about $\frac{1}{2}$ in. and the end plates about $\frac{5}{8}$ in. The safe working pressure was about 60 lb. per sq. in. Now the conditions are somewhat altered. Steel has taken the place of iron, giving increased strength, and allowing increased diameter and increased pressure. Ring plates have also abolished a great source of weakness in a boiler, namely, horizontally riveted joints. A good Lancashire boiler now will measure 8 ft. in diameter and 30 ft. long, with ring plates $\frac{5}{8}$ in. thick, end plates probably $\frac{3}{4}$ in., and will work very well at 120 lb. pressure per sq. in.

Horsepower of Boilers.—The horsepower of a boiler is a measure of its capacity for generating steam. Boilermakers usually rate the horsepower of their boilers as a certain fraction of the heating surface; but this is a very indefinite method, for with the same heating surface, different boilers of the same type may, under different circumstances, generate different quantities of steam.

In order to have an accurate standard of boiler power, the American Society of Mechanical Engineers has adopted as a standard horsepower *an evaporation of 30 lb. of water per hour from a feedwater temperature of 100° F. into steam at 70 lb. gauge pressure*, which is considered equivalent to 34.5 units of evaporation; that is, to 34.5 lb. of water evaporated from a feedwater temperature of 212° F. into steam at the same temperature.

EXAMPLE.—A boiler evaporates per hour 1,980 lb. of water from a feed temperature of 100° into steam at 70 lb. gauge pressure. What is the horsepower of the boiler?

Since, under the given conditions, an evaporation of 30 lb. is equivalent to 1 horsepower, the number of horsepower is $1,980 \div 30 = 66$.

In the various types of boilers there is a nearly constant ratio between the water-heating surface and the horsepower, and also between the heating surface and the grate area. These ratios are given in the table on page 178.

If the heating surface of a boiler is known, the horsepower can be found roughly; thus, if a return-tubular boiler has a heating surface of 900 sq. ft., its horsepower lies between $\frac{900}{18} = 50$ H. P. and $\frac{900}{14} = 64.3$ H. P., say about 57 H. P.

The **heating surface** of a boiler is the portion of the surface exposed to the action of flames and hot gases. This includes, in the case of the multitubular boiler, the portions of the shell below the line of brickwork, the exposed heads of the shell, and the interior surface of the tubes. In the

case of a water-tube boiler, the heating surface comprises the portion of the shell below the brickwork, the outer surface of the headers, and outer surface of tubes. In any given case, the heating surface may be calculated

RATIO OF HEATING SURFACE TO HORSEPOWER AND OF HEATING SURFACE TO GRATE AREA.

Type of Boiler.	Ratio $= \frac{\text{Heating Surface}}{\text{Horsepower}}$.	Ratio $= \frac{\text{Heating Surface}}{\text{Grate Area}}$.
Plain cylindrical	6 to 10	12 to 15
Flue	8 to 12	20 to 25
Return - tubular	14 to 18	25 to 35
Vertical	15 to 20	25 to 30
Water-tube	10 to 12	35 to 40
Locomotive	1 to 2	50 to 100

by the rules of mensuration. The following example will show the method of calculating the heating surface of a return-tubular boiler:

EXAMPLE.—A horizontal return-tubular boiler has the following dimensions: Diameter, 60 in.; length of tubes, 12 ft.; internal diameter of tubes, 3 in.; number of tubes, 82. Assume that $\frac{2}{3}$ of the shell is in contact with hot gases or flame, and $\frac{2}{3}$ of the two heads are heating surface.

Circumference of shell $= 60 \times 3.1416 = 188.496 = 188.5$ in., say.
Length of shell $= 12 \times 12 = 144$ in.
Heating surface of shell $= 188.5 \times 144 \times \frac{2}{3} = 18{,}096$ sq. in.
Circumference of tube $= 3 \times 3.1416 = 9.425$ in., nearly.
Heating surface of tubes $= 82 \times 144 \times 9.425 = 111{,}290.4$ sq. in.
Area of one head $= 60^2 \times .7854 = 2{,}827.44$ sq. in.
Two-thirds area of both heads $= \frac{2}{3} \times 2 \times 2{,}827.44 = 3{,}769.92$ sq. in.

From the heads must be subtracted twice the area cut out by the tubes; this is $82 \times 3^2 \times .7854 \times 2 = 1{,}159.26$.

Total heating surface in square feet =

$$\frac{18{,}096 + 111{,}290.4 + 3{,}769.92 - 1{,}159.26}{144} = 916.64 \text{ sq. ft. Ans.}$$

PROBABLE MAXIMUM WORK OF A PLAIN CYLINDRICAL BOILER OF 120 SQ. FT. HEATING SURFACE AND 12 SQ. FT. GRATE SURFACE, AT DIFFERENT RATES OF DRIVING.

Rate of driving; lb. water evaporated per sq. ft. of heating surface per hour	2	3	3.5	4	4.5	5	6	7	8
Total water evaporated by 120 sq. ft. heating surface per hour, lb.	240.00	360.00	420.00	480.00	540.00	600.00	720.00	840.00	960.00
Horsepower; 34.5 lb. per hour = 1 H. P.	6.96	10.43	12.17	13.91	15.65	17.39	20.87	24.35	27.83
Pounds water evaporated per lb. combustible	10.88	11.30	11.36	11.29	11.20	11.05	10.48	9.48	8.22
Pounds combustible burned per hour	22.10	31.90	37.00	42.50	48.20	54.30	68.70	88.60	116.80
Pounds combustible per hour per sq. ft. of grate	1.85	2.65	3.08	3.55	4.02	4.52	5.72	7.38	9.73
Pounds combustible per hour per horsepower	3.17	3.05	3.04	3.06	3.08	3.12	3.30	3.64	4.16

From the figures in the last line, we see that the amount of fuel required for a given horsepower is nearly 37% greater when the rate of evaporation is 8 lb. than when it is 3.5 lb.

The figures in the preceding table that represent the economy of fuel, viz., "Pounds water evaporated per lb. combustible" and "Pounds combustible per hour per horsepower," are what may be called "maximum" results, and they are the highest that are likely to be obtained with anthracite coal, with the most skilful firing and with every other condition most favorable. Unfavorable conditions, such as poor firing, scale on the inside of the heating surface, dust or soot on the outside, imperfect protection of the top of the boiler from radiation, leaks of air through the brickwork, or leaks of water through the blow-off pipe, may greatly reduce these figures.

Choice of a Boiler.—Questions that arise under this head in regard to any boiler are:

1. Is the grate surface sufficient for burning the maximum quantity of coal expected to be used at any time, taking into consideration the available draft, the quality of the coal, its percentage of ash, whether or not the ash tends to run into clinker, and the facilities, such as shaking grates, for getting rid of the ash or clinker?

2. Is the furnace of a kind adapted to burn the particular kind of coal used?

3. Is the heating surface of extent sufficient to absorb so much of the heat generated that the gases escaping into the chimney shall be reasonably low in temperature, say not over 450° F. with anthracite, and 550° F. with bituminous coal?

4. Are the gas passages so designed and arranged as to compel the gas to traverse at a uniform rate the whole of the heating surface, being not so large at any point as to allow of the gas finding a path of least resistance, or short-circuiting, or, on the other hand, so contracted at any point as to cause an obstruction to the draft?

These questions being settled in favor of any given boiler—and they may be answered favorably for boilers of many of the common types—the relative merits of the different types may now be considered with reference to their danger of explosion; their probable durability; the character and extent of repairs that may be needed from time to time, and the difficulty, delay, and expense that these may entail; the accessibility of every part of the boiler to inspection, internal and external; the facility for removal of mud and scale from every portion of the inner surface, and of dust and soot from the exterior; the water and steam capacity; the steadiness of water level, and the arrangements for securing dry steam.

Each one of the points referred to above should be considered carefully by the intending purchaser of any type of boiler with which he is not familiar by experience. The several points may be considered more in detail.

Danger of Explosion.—All boilers may be exploded by overpressure, such as might be caused by the combination of an inattentive fireman and an inoperative safety valve, or by corrosion weakening the boiler to such an extent as to make it unable to resist the regular working pressure; but some boilers are much more liable to explosion than others. In considering the probability of explosion of any boiler of recent design, it is well to study it to discover whether or not it has any of the features that are known to be dangerous in the plain cylinder, the horizontal tubular, the vertical tubular, and the locomotive boilers. The plain cylinder boiler is liable to explosion from strains induced by its method of suspension, and by changes of temperature. Alternate expansion and contraction may produce a line of weakness in one of the rings, which may finally cause an explosion. A boiler should be so suspended that all its parts are free to change their position under changes of temperature without straining any part. The circulation of water in the boiler should be sufficient to keep all parts at nearly the same temperature. Cold feedwater should not be allowed to come in contact with the shell, as this will cause contraction and strain. The horizontal tubular boiler, and all externally-fired shell boilers, are liable to explosion from overheating of the shell, due to accumulation of mud, scale, or grease, on the portion of the shell lying directly over the fire, to a double thickness of iron with rivets, together with some scale, over the fire, or to low water uncovering and exposing an unriveted part of the shell directly to the hot gases. Vertical tubular boilers are liable to explosion from deposit of mud, scale, or grease, upon the lower tube-sheet, and from low water allowing the upper part of the tubes to get hot and cease to act as stays to the upper tube-sheet. Locomotive boilers may explode from deposits on the crown sheet, from low water exposing the dry crown sheet

to the hot gases, and from corrosion of the staybolts. Double-cylinder boilers, such as the French elephant boiler, and the boilers used at some American blast furnaces, have exploded on account of the formation of a "steam pocket" on the upper portion of the lower drum, the steam being prevented from escaping from out of the rings of the drum by the lap joint of the adjoining ring, thus making a layer of steam about ¼ inch thick against the shell, which was directly exposed to the hot gases.

Questions to Be Asked Concerning New Boilers.—The causes mentioned above are only a few of the causes of explosions, but they are the principal ones that are due to features of design. These features should be looked for in any new style of boiler, and if they are found they should be considered elements of danger. Such questions as the following may be asked: Is the method of suspension of the boiler such as to allow its parts to be free to move under changes of temperature? Is the circulation such as to keep all parts at practically the same temperature? Is there a shell with riveted seams exposed to the fire? Is there a shell exposed to the fire that may at any time be uncovered by water? Is there a crown sheet on which scale may lodge? Are there vertical or inclined tubes acting as stays to an upper sheet, the upper part of which tubes may become overheated in case of low water? Are there any stayed sheets, the stays of which are liable to become corroded? Is there any chance for a steam pocket to be formed on a sheet that is exposed to the fire?

In addition to the above-mentioned features of design, which are elements of danger, all boilers, as already stated, are liable to explosion due to corrosion. Internal corrosion is usually due to acid feedwater, and all boilers are equally liable to it. External corrosion, however, is more liable to take place in some designs of boilers than others, and in some locations rather than others. If any portion of a boiler is in a cold and damp place, it is liable to rust out. For this reason the mud-drums of many modern forms of boilers are made of cast iron, and resist rusting better than either wrought iron or steel. If any part of a boiler, other than a part made of cast iron, is liable to be exposed to a cold and damp atmosphere, or covered with damp soot or ashes, or exposed to drip from rain or from leaky pipes, and especially if such part is hidden by brickwork or otherwise so that it cannot be seen, that part is an element of danger.

Durability.—The question of durability is partly covered by that of danger of explosion, which has already been discussed, but it also is related to the question of incrustation and scale. The plates and tubes of a boiler may be destroyed by internal or external corrosion, but they may also be burned out. It may be regarded as impossible to burn a plate or tube of iron or steel, no matter how high the temperature of the flame, provided one side of the metal is covered with water. If a steam pocket is formed, so that the water does not touch the metal, or if there is a layer of grease or hard scale, then the plate or tube may be burned. In a water tube that is horizontal, or nearly so, and in which the circulation of water is defective, it is possible to form a mass of steam that will drive the water away from the metal, and thus allow the tube to burn out. In considering the probable durability of a boiler, we may ask the same questions as those that have been asked concerning danger of explosion. There are, however, many chances of burning out a minor part of a boiler without serious danger, to one chance of a disastrous explosion. Thus the tubes of a water-tube boiler, if allowed to become thickly covered with scale, might be burned out again and again without causing any further destruction at any one time than the rupture of a single tube. A new type of boiler should be questioned in regard to the likelihood of frequent small repairs being necessary, as well as in regard to its liability to complete destruction. We may ask: Is the circulation through all parts of the boiler such that the water cannot be driven out of any tube or from any portion of a plate, so as to form a steam pocket exposed to high temperature? Are there proper facilities for removing the scale from every portion of the plates and tubes?

Repairs.—The questions of durability and of repairs are, in some respects, related to each other. The more infrequent and the less extensive the repairs, the greater the durability. The tubes of a boiler, where corroded or burnt out, may be replaced and made as good as new. The shell, when it springs a leak, may be patched, and is then likely to be far from as good as new. When the shell corrodes badly it must be replaced, and to replace the shell is the same as getting a new boiler. Herein is the advantage of the sectional water-tube boilers. The sections, or parts of a section, may be

renewed easily, and made as good as new, while the shell, being far removed from the fire and easily kept dry externally, is not liable either to burning out or external corrosion. In considering the merits of a new style of boiler, with reference to repairs, we may ask what parts of the boiler are most likely to give out and need to be repaired or replaced? Are these repairs easily effected, how long will they require, and, after they are made, is the boiler as good as new?

Facility for Removal of Scale and for Inspection.—These questions have already been discussed to some extent under the head of durability. Some water-tube boilers, now dead and gone, were some years ago put on the market, which had no facilities for the removal of scale. It was claimed by their promoters that they did not need any, because their circulation was so rapid. Every few years boilers of these types are reinvented, and the same claim is made for them, that their rapid circulation prevents the formation of scale. The fact is that if there is scale-forming material in the water it will be deposited when the water is evaporated, and no amount or kind of circulation will keep it from accumulating on every part of the boiler, and in every kind of tubes, vertical, horizontal, and inclined. I have seen the nearly vertical circulating tubes of a water-tube boiler, in which the circulation is nine times as fast as the average circulation in the inclined tubes, nearly full of scale; that is, a 4″ tube had an opening in it of less than 1 in. in diameter. This was due to carelessness in blowing off the boiler, or exceptionally bad feedwater, or both. If circulation would prevent scaling at all, it would prevent it here.

Water and Steam Capacity.—It is claimed for some forms of boilers that they are better than others because they have a larger water or steam capacity. Great water capacity is useful where the demands for steam are extremely fluctuating, as in a rolling mill or a sugar refinery, where it is desirable to store up heat in the water in the boilers during the periods of the least demand, to be given out during periods of greatest demand. Large water capacity is objectionable in boilers for factories, usually, especially if they do not run at night, and the boilers are cooled down, because there is a large quantity of water to be heated before starting each morning. If "rapid steaming" or the ability to get up steam quickly from cold water, or to raise the pressure quickly, is desired, large water capacity is a detriment. The advantage of large steam capacity is usually overrated. It is useful to enable the steam to be drained from water before it escapes into the steam pipe, but the same result can be effected by means of a dry pipe, as in locomotive and marine practice, in which the steam space in the boiler is very small in proportion to the horsepower. Large steam space in the boiler is of no importance for storing energy or equalizing the pressure during the stroke of an engine. The water in the boiler is the place to store heat, and if the steam pipe leading to an engine is of such small capacity that it reduces the pressure, the remedy is a steam reservoir close to the engine or a large steam pipe.

Steadiness of Water Level.—This requires either a large area of water surface, so that the level may be changed slowly by fluctuations in the demand for steam or in the delivery of the feed-pump, or else constant, and preferably automatic, regulation of the feedwater supply to suit the steam demand. A rapidly lowering water level is apt to expose dry sheets or tubes to the action of the hot gases, and thus be a source of danger. A rapidly rising level may, before it is seen by the fireman, cause water to be carried over into the steam pipe, and endanger the engine.

Water Circulation.—Positive and complete circulation of the water in a boiler is important for two reasons: (1) To keep all parts of the boiler of a uniform temperature, and (2) to prevent the adhesion of steam bubbles to the surface, which may cause overheating of the metal. It is claimed by some manufacturers that the rapid circulation of water in their boilers tends to make them more economical than others. I have as yet, however, to find any proof that increased rapidity of circulation of water beyond that usually found in any boiler will give increased economy. We know that increased rate of flow of air over radiating surfaces increases the amount of heat transmitted through the surface, but this is because by the increased circulation, cold air is continually brought into contact with the surface, making an increased difference of temperature on the two sides, which causes increased transmission. But by increasing the rapidity of circulation in a steam boiler we cannot vary the difference of temperature to any appreciable extent, for the water and the steam in the boiler are at

about the same temperature throughout. The ordinary or "Scotch" form of marine boiler shows an exception to the general rule of uniformity of temperature of water throughout the boiler, but the temperature above the level of the lower fire tubes is practically uniform.

INCRUSTATION AND SCALE.

Nearly all waters contain foreign substances in a greater or less degree, and though this may be a small amount in each gallon, it becomes of importance where large quantities are evaporated. For instance, a 100 H. P. boiler evaporates 30,000 lb. of water in 10 hours, or 390 *tons* per month; in comparatively pure water there would be 88 lb. of solid matter in that quantity, and in many kinds of spring water as much as 2,000 lb.

The nature and hardness of the scale formed of this matter will depend on the kind of substances held in solution and suspension. Analyses of a great variety of incrustations show that carbonate and sulphate of lime form the larger part of all ordinary scale, that from carbonate being soft and granular, and that from sulphate, hard and crystalline. Organic substances in connection with carbonate of lime will also make a hard and troublesome scale.

The presence of scale or sediment in a boiler results in loss of fuel, burning and cracking of the boiler, predisposes to explosion, and leads to extensive repairs. It is estimated that the presence of $\frac{1}{16}$ in. of scale causes a loss of 13% of fuel; $\frac{1}{4}$ in., 38%; and $\frac{1}{2}$ in., 60%. The Railway Master Mechanics' Association of the United States estimates that the loss of fuel, extra repairs, etc., due to incrustation, amount to an average of $750 per annum for every locomotive in the Middle and Western States, and it must be nearly the same for the same power in stationary boilers.

Causes of Incrustation.—

1. Deposition of suspended matter.
2. Deposition of salts from concentration.
3. Deposition of carbonates of lime and magnesia, by boiling off carbonic acid, which holds them in solution.
4. Deposition of sulphates of lime, because sulphate of lime is soluble in cold water, less soluble in hot water, insoluble above 270° F.
5. Deposit of magnesia, because magnesium salts decompose at high temperatures.
6. Deposition of lime soap, iron soap, etc., formed by saponification of grease.

Method of Preventing Incrustation.—

1. Filtration.
2. Blowing off.
3. Use of internal collecting apparatus, or devices, for directing the circulation.
4. Heating feedwater.
5. Chemical or other treatment of water in boiler.
6. Introduction of zinc in boiler.
7. Chemical treatment of water outside of boiler.

Troublesome Substance.	Trouble.	Remedy or Palliation.
Sediment, mud, clay, etc.	Incrustation.	Filtration; blowing off.
Readily soluble salts.	Incrustation.	Blowing off.
Bicarbonates of lime, magnesia, and iron.	Incrustation.	Heating feed; addition of caustic soda, lime, or magnesia, etc.
Sulphate of lime.	Incrustation.	Addition of carbonate of soda, barium chloride, etc.
Chloride and sulphate of magnesium.	Corrosion.	Addition of carbonate soda, etc.
Carbonate of soda in large amounts.	Priming.	Addition of barium chloride, etc.
Acid (in mine water).	Corrosion.	Alkali.
Dissolved carbonic acid and oxygen.	Corrosion.	Heating feed; addition of caustic soda, slaked lime, etc.
Grease (from condensed water).	Corrosion.	Slaked lime and filtering. Substitute mineral oil.
Organic matter (sewage).	Priming.	Precipitate with alum or ferric chloride and filter.
Organic matter.	Corrosion.	Precipitate with alum or ferric chloride, and filter.

Means of Prevention.—It is absolutely essential to the successful use of any boiler, except in pure water, that it be accessible for the removal of scale, for though a rapid circulation of water will delay the deposit, and certain chemicals will change its character, yet the most certain cure is periodical inspection and mechanical cleaning. This may, however, be rendered less frequently necessary, and the use of very bad water more practical by the employment of some preventives. The following are fair samples of those in use, with their results:

M. Bidard's observations show that "anti-incrustators" containing organic matter help rather than hinder incrustations, and are therefore to be avoided.

Oak, hemlock, and other barks and woods, sumac, catechu, logwood, etc. are effective in waters containing carbonates of lime or magnesia, by reason of their tannic acid, but are injurious to the iron and not to be recommended.

Molasses, cane juice, vinegar, fruits, distillery slops, etc. have been used with success so far as scale is concerned, by reason of the acetic acid that they contain, but this is even more injurious to the iron than tannic acid, while the organic matter forms a scale with sulphate of lime when it is present.

Milk of lime and metallic zinc have been used with success in waters charged with bicarbonate of lime, reducing the bicarbonate to the insoluble carbonate.

Barium chloride and milk of lime are said to be used with good effect at Krupp's works, in Prussia, for waters impregnated with gypsum.

Soda ash and other alkalies are very useful in waters containing sulphate of lime, by converting it into a carbonate, and so forming a soft scale easily cleaned. But when used in excess they cause foaming, particularly where there is oil coming from the engine, with which they form soap. All soapy substances are objectionable for the same reason.

Petroleum has been much used of late years. It acts best in waters in which sulphate of lime predominates. Sulphate of lime is the injurious substance in nearly all mine waters, and petroleum, when properly prepared, is a good preventive of scale and pitting. Crude petroleum should not be used, as it sometimes helps in forming a very injurious scale. Refined petroleum, on the other hand, is useless, as it vaporizes at a temperature below that of boiling water. Therefore, only such preparations should be used as will not vaporize below 500° F.

Tannate of soda is a good preparation for general use, but in waters containing much sulphate, it should be supplemented by a portion of carbonate of soda or soda ash.

A decoction from the leaves of the eucalyptus is found to work well in some waters in California.

For muddy water, particularly if it contain salts of lime, no preventive of incrustation will prevail except filtration, and in almost every instance the use of a filter, either alone or in connection with some means of precipitating the solid matter from solution, will be found very desirable.

In all cases where impure or hard waters are used, frequent "blowing" from the mud-drum is necessary to carry off the accumulated matter, which if allowed to remain would form scale.

When boilers are coated with a hard scale, difficult to remove, it will be found that the addition of ¼ lb. caustic soda per horsepower, and steaming for some hours, according to the thickness of the scale, just before cleaning, will greatly facilitate that operation, rendering the scale soft and loose. This should be done, if possible, when the boilers are not otherwise in use.

COVERING FOR BOILERS, STEAM PIPES, ETC.

The losses by radiation from unclothed pipes and vessels containing steam are considerable, and in the case of pipes leading to steam engines, are magnified by the action of the condensed water in the cylinder. It therefore is important that such pipes should be well protected. The following table gives the loss of heat from steam pipes naked, and clothed with wool or hair felt, of different thickness, the steam pressure being assumed at 75 lb., and the exterior air at 60°.

There is a wide difference in the value of different substances for protection from radiation, their values varying nearly in the reverse ratio to their conducting power for heat, up to their ability to transmit as much heat as

the surface of the pipe will radiate, after which they become detrimental, rather than useful, as covering. This point is reached nearly at baked clay or brick.

TABLE OF LOSS OF HEAT FROM STEAM PIPES.

Thickness of Covering. Inches.	Outside Diameter of Pipe, Without Felt.														
	2 In. Diameter.			4 In. Diameter.			6 In. Diameter.			8 In. Diameter.			12 In. Diameter.		
	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in Length per H. P. Lost.	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in Length per H. P. Lost.	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in Length per H. P. Lost.	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in Length per H. P. Lost.	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in Length per H. P. Lost.
0	219.0	1.00	132	390.8	1.00	75	624.1	1.000	46	729.8	1.000	40	1,077.4	1.000	26
$\frac{1}{4}$	100.7	.46	288	180.9	.46	160									
$\frac{1}{2}$	65.7	.30	441	117.2	.30	247	187.2	.300	154	219.6	.301	132	301.7	.280	92
1	43.8	.20	662	73.9	.18	392	111.0	.178	261	128.3	.176	225	185.3	.172	157
2	28.4	.13	1,020	44.7	.11	648	66.2	.106	438	75.2	.103	385	98.0	.091	294
4	19.8	.09	1,464	28.1	.07	1,031	41.2	.066	703	46.0	.063	630	60.3	.056	486
6				23.4	.06	1,238	33.7	.054	860	34.3	.047	845	45.2	.042	642

A smooth or polished surface is of itself a good protection, polished tin or Russia iron having a ratio, for radiation, of 53 to 100 for cast iron. Mere color makes but little difference.

TABLE OF CONDUCTING POWER OF VARIOUS SUBSTANCES.

(*From Péclet.*)

Substance.	Conducting Power.	Substance.	Conducting Power.
Blotting paper	.274	Wood, across fiber	.83
Eiderdown	.314	Cork	1.15
Cotton or Wool, any density	.323	Coke, pulverized	1.29
		India rubber	1.37
Hemp, canvas	.418	Wood, with fiber	1.40
Mahogany dust	.523	Plaster of Paris	3.86
Wood ashes	.531	Baked clay	4.83
Straw	.563	Glass	6.60
Charcoal powder	.636	Stone	13.68

Hair or wool felt has the disadvantage of becoming soon charred from the heat of steam at high pressure, and sometimes of taking fire therefrom. This has led to a variety of "cements" for covering pipes—composed generally of clay mixed with different substances, as asbestos, paper fiber, charcoal, etc. A series of careful experiments, made at the Massachusetts Institute of Technology in 1871, showed the condensation of steam in a pipe covered by one of them, as compared with a naked pipe, and one clothed with hair felt, was 100 for the naked pipe, 67 for the "cement" covering, and 27 for the hair felt.

The presence of sulphur in the best coverings and its recognized injurious effects make it imperative that moisture be kept from the coverings, for, if present, it will surely combine with the sulphur, thus making it active. Stated in other words, keep the pipes and coverings in good repair. Much of the inefficiency of coverings is due to the lack of attention given them; they are often seen hanging loosely from the pipe which they are supposed to protect.

TABLE OF RELATIVE VALUE OF NON-CONDUCTORS.
(*From Chas. E. Emery, Ph. D.*)

Non-Conductor.	Value.	Non-Conductor.	Value.
Wool felt	1.000	Loam, dry and open	.550
Mineral wool No. 2	.832	Slaked lime	.480
Mineral with tar	.715	Gas-house carbon	.470
Sawdust	.680	Asbestos	.363
Mineral wool No. 1	.676	Coal ashes	.345
Charcoal	.632	Coke in lumps	.277
Pine wood across fiber	.553	Air space undivided	.136

Carbonate of magnesia, as compared with wool felt at 1.000, has a relative value of .472. This is determined from tests by Prof. Ordway, of Boston, and adjusted to results shown in Prof. Emery's tests.

"Mineral wool," a fibrous material made from blast-furnace slag, is a good protection, and is incombustible.

Cork chips, cemented together with water glass, make one of the best coverings known.

A cheap jacketing for steam pipes, but a very efficient one, may be applied as follows: First, wrap the pipe in asbestos paper, though this may be dispensed with; then lay slips of wood lengthways, from 6 to 12, according to size of pipe, binding them in position with wire or cord, and around the framework thus constructed wrap roofing paper, fastening it by paste or twine. For flanged pipe, space may be left for access to the bolts, which space should be filled with felt. If exposed to weather, use tarred paper, or paint the exterior. A French plan is to cover the surface with a rough flour paste, mixed with sawdust until it forms a moderately stiff dough. Apply with a trowel in layers of about ¼ in. thick; give 4 or 5 layers in all. If iron surfaces are well cleaned from grease, the adhesion is perfect. For copper, first apply a hot solution of clay in water. A coating of tar renders the composition impervious to the weather.

DATA FOR PROPORTIONING AN ECONOMIZER.

(*The Green Fuel Economizer Co., Matteawan, N. Y.*)

The following estimate is given for the amount of heating surface to be provided in an economizer to be used in connection with a given amount of boilers:

By allowing 4 sq. ft. of heating surface per boiler horsepower (Centennial rating, 34½ lb. of water evaporated from and at 212° = 1 H. P.), we are able to raise the feedwater 60° for every 100° reduction in the temperature entering the economizer with gases from 450° to 600°. These results are corroborated by Mr. Barrus's tests.

With the temperature of the gases entering the economizer at 600° to 700°, we have allowed 4½ to 5 sq. ft. of heating surface per boiler horsepower, and for every 100° reduction of gases we have obtained about 65° rise in temperature of the water; the temperature of the feedwater entering averaging from 60° to 120°.

With 5,000 sq. ft. of boiler heating surface (plain cylinder boilers) developing 1,000 H. P., we should recommend using 5 sq. ft. of economizer heating surface per B. H. P., or an economizer of about 500 tubes, and it should heat the feedwater about 300°.

CARE OF BOILERS.

1. **Safety Valves.**—Great care should be exercised to see that these valves are ample in size and in working order. *Overloading* or *neglect* frequently leads to the most disastrous results. Safety valves should be tried at least once every day, to see that they act freely.

2. **Pressure Gauge.**—The steam gauge should stand at zero when the pressure is off, and it should show same pressure as the safety valve when that is blowing off. If not, then one is wrong, and the gauge should be tested by one known to be correct.

3. **Water Level.**—The first duty of an engineer before starting, or at the beginning of his watch, is to see that the water is at the proper height. Do not rely on glass gauges, floats, or water alarms, but try the gauge-cocks. If they do not agree with water gauge, learn the cause and correct it.

4. **Gauge-cocks and water gauges** must be kept clean. Water gauges should be blown out frequently, and the glasses and passages to them kept clean. The Manchester, England, Boiler Association attributes more accidents to inattention to water gauges than to all other causes put together.

5. **Feed-Pump or Injector.**—These should be kept in perfect order, and be of ample size. No make of pump can be expected to be continuously reliable without regular and careful attention. It is always safe to have two means of feeding a boiler. Check-valves and self-acting feed-valves should be frequently examined and cleaned. Satisfy yourself frequently that the valve is acting when the feed-pump is at work.

6. **Low Water.**—In case of low water, immediately cover the fire with ashes (wet if possible) or any earth that may be at hand. If nothing else is handy, use fresh coal. Draw fire as soon as it can be done without increasing the heat. Neither turn on the feed, start nor stop engine, nor lift safety valve until fires are out and the boiler cooled down.

7. **Blisters and Cracks.**—These are liable to occur in the best plate iron. When the first indication appears, there must be no delay in having it carefully examined and properly cared for.

8. **Fusible plugs,** when used, must be examined when the boiler is cleaned, and carefully scraped clean on both the water and fire sides, or they are liable not to act.

9. **Firing.**—Fire evenly and regularly, a little at a time. Moderately thick fires are most economical, but thin firing must be used where the draft is poor. Take care to keep grates evenly covered, and allow no air holes in the fire. Do not "clean" fires oftener than necessary. With bituminous coal, a "coking fire," i. e., firing in front and shoving back when coked, gives best results if properly managed.

10. **Cleaning.**—All heating surfaces must be kept clean outside and in, or there will be a serious waste of fuel. The frequency of cleaning will depend on the nature of fuel and water. When a new feedwater supply is introduced, its effect upon the boiler should be closely observed, as this new supply may be either an advantage or a detriment as compared with the working of the boiler previous to its introduction. As a rule, never allow over $\frac{1}{16}''$ scale or soot to collect on surfaces between cleanings. Handholes should be frequently removed and surfaces examined, particularly in case of a new boiler, until proper intervals have been established by experience.

The **exterior** of tubes can be kept clean by the use of blowing pipe and hose through openings provided for that purpose. In using smoky fuel, it is best to occasionally brush the surfaces when steam is off.

11. **Hot Feedwater.**—Cold water should never be fed into any boiler when it can be avoided, but when necessary it should be caused to mix with the heated water before coming in contact with any portion of the boiler.

12. **Foaming.**—When foaming occurs in a boiler, checking the outflow of steam will usually stop it. If caused by dirty water, blowing down and pumping up will generally cure it. In cases of violent foaming, check the draft and fires.

13. **Air Leaks.**—Be sure that all openings for admission of air to boiler or flues, except through the fire, are carefully stopped. This is frequently an unsuspected cause of serious waste.

14. **Blowing Off.**—If feedwater is muddy or salt, blow off a portion frequently, according to condition of water. Empty the boiler every week or two, and fill up afresh. When surface blow cocks are used, they should be often opened for a few minutes at a time. Make sure no water is escaping from the blow-off cock when it is supposed to be closed. Blow-off cocks and check-valves should be examined every time the boiler is cleaned. Never empty the boiler while the brickwork is hot.

15. **Leaks.**—When leaks are discovered, they should be repaired as soon as possible.

16. **Filling Up.**—Never pump cold water into a hot boiler. Many times leaks, and, in shell boilers, serious weaknesses, and sometimes explosions are the result of such an action.

17. **Dampness.**—Take care that no water comes in contact with the exterior of the boiler from any cause, as it tends to corrode and weaken the boiler. Beware of all dampness in seatings and coverings.

18. **Galvanic Action.**—Examine frequently parts in contact with copper or brass, where water is present, for signs of corrosion. If water is salt or acid, some metallic zinc placed in the boiler will usually prevent corrosion, but it will need attention and renewal from time to time.

19. **Rapid Firing.**—In boilers with thick plates or seams exposed to the fire, steam should be raised slowly, and rapid or intense firing avoided. With thin water tubes, however, and adequate water circulation, no damage can come from that cause.

20. **Standing Unused.**—If a boiler is not required for some time, empty and dry it thoroughly. If this is impracticable, fill it quite full of water, and put in a quantity of common washing soda. External parts exposed to dampness should receive a coating of linseed oil.

21. **Repair of Coverings.**—All coverings should be looked after at least once a year, given necessary repairs, refitted to the pipe, and the spaces due to shrinkage taken up. Little can be expected from the best non-conductors if they are allowed to become saturated with water, or if air-currents are permitted to circulate between them and the pipe.

22. **General Cleanliness.**—All things about the boiler room should be kept clean and in good order. Negligence tends to waste and decay.

THICKNESS OF BOILER IRON REQUIRED AND PRESSURE ALLOWED BY THE LAWS OF THE UNITED STATES.

PRESSURE EQUIVALENT TO THE STANDARD FOR A BOILER 42 IN. IN DIAMETER AND ¼ IN. THICK.

Thickness. 16ths.	Diameter.						
	34 In. Lb.	36 In. Lb.	38 In. Lb.	40 In. Lb.	42 In. Lb.	44 In. Lb.	46 In. Lb.
5	169.9	160.4	152.0	144.4	137.5	131.2	125.5
4½	158.5	149.7	141.8	134.7	128.3	122.5	117.2
4	135.9	128.3	121.6	115.5	110.0	105.0	100.0
3⅔	124.5	117.6	111.4	105.9	100.8	96.2	92.0
3⅓	113.2	106.9	101.3	96.2	91.7	87.5	83.0
3	101.9	96.2	91.2	82.6	82.5	78.7	75.1

The rule for finding the proper sectional area for the narrowest part of the nozzle is given by Rankine, S. E., page 477, as follows:

$$\text{Area in square inches} = \frac{\text{cubic feet per hour gross feedwater}}{800\sqrt{\text{pressure in atmospheres}}}.$$

Diameter of Throat. Decimals of an Inch.	Delivery in Gallons per Hour with a Pressure per Square Inch of				
	30 Lb.	45 Lb.	60 Lb.	75 Lb.	90 Lb.
.10	56	69	80	89	98
.15	127	156	180	201	221
.20	226	278	321	360	393
.25	354	434	502	561	615
.30	505	624	722	807	884

Pressure of Steam at Different Temperatures.

(Results of Experiments Made by the Franklin Institute.)

Pressure. Inches of Mercury.	Temperature. Degrees F.	Pressure. Inches of Mercury.	Temperature. Degrees F.	Pressure. Inches of Mercury.	Temperature. Degrees F.
30	212.0	135	298.5	225	331.0
45	235.0	150	304.5	240	336.0
60	250.0	165	310.0	255	340.5
75	264.0	180	315.5	270	345.0
90	275.0	195	321.0	285	349.0
105	284.0	210	326.0	300	352.5
120	291.5				

Maximum Economy of Plain Cylinder Boilers.

	Pounds of Water Evaporated From and at 212°.										
Per sq. ft. heating surface per hour	1.70	2.00	2.60		3.50	4.00	4.50	5.00	6.00	7.00	8.00
Per lb. combustible, maximum of other boilers, Centennial tests	11.90	12.00	12.10	12.05	12.00	11.85	11.70	11.50	10.85	9.80	8.50
Subtract extra radiation loss for cylinder boilers	1.32	1.12	.87	.75	.64	.56	.50	.45	.37	.32	.28
Probable maximum per lb. combustible, cylinder boilers	10.58	10.88	11.23	11.30	11.36	11.29	11.20	11.05	10.48	9.48	8.22

Scheme for Boiler Test.

1	Number of test	
2	Made by	
3	Type of boiler	
4	Date of test	
5	Duration of test	Hr.
	Dimensions and Proportions.	
6	Number of boilers tested	
7	Diameter, boiler	In.
8	Length, boiler	Ft. In.
9	Width, grate	Ft. In.
10	Length, grate	Ft. In.
11	Number of tubes	No.
12	Diameter of tubes	In.
13	Length of tubes	Ft. In.
14	Total water heating surface	Sq. Ft.
15	Total steam heating surface	Sq. Ft.
16	Grate surface per boiler	Sq. Ft.
17	Per cent. air space in grate	%
18	Ratio water heating to grate surface	
19	Area of stack	Sq. Ft.
20	Height stack above dead plates	Ft.
21	Ratio stack area to grate surface	
	Average Pressures.	
22	Atmosphere by barometer	In.
23	Steam pressure by gauge	Lb.

SCHEME FOR BOILER TEST—(*Continued*).

24	Force chimney draft, inches water	In.
25	Force blast in ash pit, inches water	In.
	Average Temperatures.	
26	Of external air	°F.
27	Of fireroom	°F.
28	Of steam	°F.
29	Of feedwater before heater	°F.
30	Of feedwater after heater	°F.
31	Of stack gases	°F.
	Fuel.	
32	Kind of coal	
33	Total coal consumed	Lb.
34	Moisture in coal	%
35	Total dry coal consumed	Lb.
36	Total ash and refuse	Lb.
37	Per cent. ash and refuse in dry coal	%
38	Total combustible consumed	Lb.
	CALORIMETRIC TESTS.	
39	Per cent. moisture in steam	%
40	Degrees superheat in steam	°F.
	Water.	
41	Total water pumped into boiler	Lb.
42	Water evaporated corrected for quality of steam	Lb.
43	Equiv. water evap. to dry steam from and at 212°	Lb.
44	Equiv. water evap. to dry steam from and at 212° per hour	Lb.
	Economic Evaporation.	
45	Water evap. per lb. dry coal actual pressures and temp.	Lb.
46	Equiv. water evap. lb. dry coal from and at 212°	Lb.
47	Equiv. water evap. lb. combustible from and at 212°	Lb.
	Rate of Combustion.	
48	Dry coal burned per hr. per sq. ft. grate surface	Lb.
49	Combustible burned per hr. per sq. ft. grate surface	Lb.
50	Dry coal per hour per H. P. developed	Lb.
	Rate of Evaporation.	
51	Water evap. from and at 212° per hour — Per sq. ft. grate surface	Lb.
52	Water evap. from and at 212° per hour — Per sq. ft. heating surface	Lb.
	Commercial Horsepower.	
53	Basis 20 lb. water from 100° feed to 70 lb. steam per hour	H. P.
54	Horsepower builders rating	H. P.
55	Heating surface to one horsepower developed	Sq. Ft.
56	Per cent. total horsepower due to feedheater	%

CHIMNEYS.

Chimneys have two important duties to perform, the first being to carry off the waste furnace gases, which requires size, and the second, to produce a draft sufficient to insure the complete combustion of the fuel, which requires height. The area of a chimney is usually made from $\frac{1}{7}$ to $\frac{1}{10}$ as large as the area of the furnace grates, or of about the same cross-section as the cross-sectional area of the flues or tubes; we have, therefore, a comparatively simple method of determining one of the required dimensions of a chimney, and, when this is known, it becomes an easy matter to determine the height of the chimney when the horsepower of the boiler has been ascertained.

The horsepower of a boiler being given, and the necessary chimney area having been determined, the following rule gives the required height that the chimney must be to produce the necessary draft:

Rule.—*From 3.33 times the area of the chimney in square feet, subtract twice the square root of the area of the chimney in square feet, and divide the given horsepower by the remainder. The square of the quotient will be the height of the chimney in feet.*

Let A = area of chimney;
H = horsepower of boiler;
h = height of chimney.

Then,
$$h = \left(\frac{H}{3.33\,A - 2\sqrt{A}}\right)^2.$$

Example.—What must be the height of a chimney that is to have a cross-sectional area of 7 sq. ft., and to supply the draft for a 141-horsepower boiler?

$$h = \left(\frac{141}{3.33 \times 7 - 2\sqrt{7}}\right)^2 = \left(\frac{141}{3.33 \times 7 - (2 \times 2.65)}\right)^2 = 61.3 \text{ ft. Ans.}$$

Forced Draft.—The use of forced draft as a substitute for, or as an aid to, natural chimney draft is becoming quite common in large boiler plants. Its advantages are that it enables a boiler to be driven to its maximum capacity to meet emergencies without reference to the state of the weather or to the character of the coal; that the draft is independent of the temperature of the chimney gases, and that therefore lower flue temperatures may be used than with natural draft; and in many cases that it enables a poorer quality of coal to be used than is required with natural draft. Forced draft may be obtained: First, by a steam jet in the chimney, as in locomotives and steam fire-engines; second, by a steam-jet blower under the grate bars; third, by a fan blower delivering air under the grate bars, the ash-pit doors being closed; fourth, by a fan blower delivering air into a closed fireroom, as in the "closed stoke-hold" system used in some ocean-going vessels; and fifth, by a fan placed in the flue or chimney drawing the gases of combustion from the boilers, commonly called the *induced-draft system*. Which one of these several systems should be adopted in any special case will usually depend on local conditions. The steam jet has the advantage of lightness and compactness of apparatus, and is therefore most suitable for locomotives and steam fire-engines, but it also is the most wasteful of steam, and therefore should not be used when one of the fan-blower systems is available, except for occasional or temporary use, or when very cheap fuel, such as anthracite culm at the coal mines, is used.

STEAM ENGINES.

What Is a Good Steam Engine?—It should be as direct acting as possible; that is, the connecting parts between the piston and the crank-shaft should be few in number, as each part wastes some power. Formerly, beam engines were all the rage. They were well enough in their time for pumping, when the pump was at one end of the beam and the piston at the other. Few of our modern colliery engines have such an appendage, except in some instances for pumping, and even for that kind of work the better engines have no beams. The moving parts of an engine should be strong, to resist strains, and light, so as to offer no undue resistance to motion; parts moving upon each other should be well and truly and smoothly finished, to reduce resistances to a minimum; the steam should get into the cylinder easily at the proper time, and the exhaust should leave the cylinder as exactly and as easily. The steam pipes supplying steam should have an area one-tenth the combined areas of the cylinders they supply, and exhaust pipes should be somewhat larger. The cylinder and the steam pipes and the boiler should be well protected. The engine should be capable of being started and stopped and reversed easily and quickly.

Rule.—*To find the indicated horsepower developed by an engine, multiply together the M. E. P. per square inch, the area of the piston, the length of stroke, and the number of strokes per minute. This gives the work per minute in foot-pounds. Divide the product by 33,000; the result will be the indicated horsepower of the engine.*

Let I. H. P. = indicated horsepower of engine;
P = M. E. P. in pounds per square inch;
A = area of piston in square inches;
L = length of stroke in feet;
N = number of strokes per minute.

Then, the above rule may be expressed thus:

$$\text{I. H. P.} = \frac{PLAN}{33{,}000}.$$

The number of strokes per minute is twice the number of revolutions per minute. For example, if an engine runs at a speed of 210 revolutions per minute, it makes 420 strokes per minute. A few types of engines, however, are single acting; that is, the steam acts on only one side of the piston. In this case, only 1 stroke per revolution does work, and, consequently, the

number of strokes per minute to be used in the above rule is the same as the number of revolutions per minute.

EXAMPLE.—The diameter of the piston of an engine is 10 in. and the length of stroke 15 in. It makes 250 revolutions per minute, with a M. E. P. of 40 lb. per sq. in. What is the horsepower?

As it is not stated whether the engine is single or double acting, assume that it is double acting. Then, the number of strokes is $250 \times 2 = 500$ per minute. Hence,

$$\text{I. H. P.} = \frac{PLAN}{33{,}000} = \frac{40 \times \frac{15}{12} \times (10^2 \times .7854) \times 500}{33{,}000} = 59.5 \text{ H. P.}$$

Approximate Determination of M. E. P.—To approximately determine the M. E. P. of an engine, when the point of apparent cut-off is known and the boiler pressure, or the pressure per square inch in the boiler from which the supply of steam is obtained, is given:

Rule.—*Add 14.7 to the gauge pressure, and multiply the result by the number opposite the fraction indicating the point of cut-off in the following table. Subtract 17 from the product, and multiply by .9. The result is the M. E. P. for good, simple non-condensing engines.*

Or, letting

$$p = \text{gauge pressure;}$$
$$k = \text{a constant (see following table);}$$
$$\text{M. E. P.} = \text{mean effective pressure.}$$

Then, $$\text{M. E. P.} = .9[k(p + 14.7) - 17].$$

TABLE.

Cut-Off.	Constant.	Cut-Off.	Constant.	Cut-Off.	Constant.
$\frac{1}{6}$	.566	$\frac{3}{8}$	.771	$\frac{2}{3}$	.917
$\frac{1}{5}$	.603	.4	.789	.7	.926
$\frac{1}{4}$	.659	$\frac{1}{2}$	.847	$\frac{3}{4}$	.937
.3	.708	.6	.895	.8	.944
$\frac{1}{3}$	.743	$\frac{5}{8}$	.904	$\frac{7}{8}$	.951

If the engine is a simple condensing one, subtract the pressure in the condenser instead of 17. The fraction indicating the point of cut-off is obtained by dividing the distance that the piston has traveled when the steam is cut off by the whole length of the stroke. For a $\frac{2}{3}$ cut-off, and 92 lb. gauge pressure in the boiler, the M. E. P. is, by the formula just given, $.9[.917(92 + 14.7) - 17] = 72.6$ lb. per sq. in.

EXAMPLE.—Find the approximate I. H. P. of a 9″ × 12″ non-condensing engine, cutting off at $\frac{1}{2}$ stroke, and making 240 revolutions per minute. The boiler pressure is 80 lb. gauge.

$80 + 14.7 = 94.7$. The constant for $\frac{1}{2}$ cut-off is .847, and .847 × boiler pressure $= .847 \times 94.7 = 80.21$. M. E. P. $= (80.21 - 17) \times .9 = 56.89$ lb. per sq. in. Then,

$$\text{I. H. P.} = \frac{PLAN}{33{,}000} = \frac{56.89 \times \frac{12}{12} \times (.7854 \times 9^2) \times 240 \times 2}{33{,}000} = 52.64 \text{ H. P. Ans.}$$

RULES FOR ENGINE DRIVERS.

If a gauge glass breaks, turn off the water first and then the steam, to avoid scalding yourself.

Don't buy oil or waste simply because it is very cheap; it will cost more than a good article in the end.

In cutting rubber for gaskets, etc., have a dish of water handy, and keep wetting the knife blade; it makes the work much easier.

Don't forget that there is no economy in employing a poor fireman. He can, and probably will, waste more coal than would pay the wages of a first-class man.

An ordinary steam engine having two cylinders connected at right angles on the same shaft consumes one-third more steam than a single-cylinder engine, while developing only the same amount of power.

A fusible plug ought to be renewed every three months, by removing the old metal and refilling the case; and it should be scraped clean and bright on both ends every time that the boiler is washed out, to keep it in good working order.

When you try a gauge-cock, don't jerk it open suddenly, for if the water happens to be a trifle below the cock, the sudden relief from pressure at that point may cause it to lift and flow out, deceiving you in regard to its height. Whereas, if you open it quietly, no lift will occur, and you ascertain surely whether there is water or steam at that level.

Always open steam stop-valves between boilers very gently, that they may heat and expand gradually. By suddenly turning on steam a stop-valve chest was burst, due to the expansive power of heat unequally applied. The same care is also recommended when shutting off stop-valves. A fearful explosion once occurred by shutting a communicating stop-valve too suddenly—due to the recoil.

In order to obtain the driest possible steam from a boiler, there should be an internal perforated pipe (dry pipe, so called) fixed near the top of the boiler, and suitably connected to the steam pipe. The perforations in this pipe should be from one-quarter to one-half greater in area than that of the steam pipe. Domes are of no use as steam driers; they only add a very little to the steam space of a boiler, and are often a source of loss by radiation.

If a glass gauge tube is too long, take a triangular file and wet it with turpentine; hold the tube in the left hand, with the thumb and forefinger at the place where you wish to cut it, saw it quickly and lightly two or three times with the edge of the file, and it will mark the glass. Now take the tube in both hands, both thumbs being on the side opposite the mark, and an inch or so apart, and then try to bend the glass, using your thumbs as fulcrums, and it will break at the mark, which has weakened the tube.

A stiff charge of coal all over a furnace will lower the temperature 200° or 300° in a very short time. After the coal is well ignited the temperature will rise about 500°, and as it continues burning will gradually drop about 200°, until the fireman puts in another charge, when the sudden fall before mentioned takes place again. This sudden contraction and expansion frequently causes the bursting of a boiler, and it is for this reason that light and frequent charges of coal, or else firing only one-half of the furnace at a time, should be always insisted on.

Be careful when using a wrench on hexagonal nuts that it fits snugly, or the edges of the nut will soon become rounded.

Be careful how you use a monkeywrench, for if it is not placed on the nut properly the strain will often bend or fracture the wrench.

The area of grate for a boiler should never be less than $\frac{1}{6}$ sq. ft. per I. H. P. of the engine, and it is seldom advisable to increase this allowance beyond $\frac{1}{3}$ sq. ft. per I. H. P.

The area of tube surface for a boiler should not be less than $2\frac{1}{4}$ sq. ft. per I. H. P. of the engine.

The ratio of heating surface to grate area in a boiler should be 30 to 1 as a minimum, and may often be increased to 40 to 1, or even more, with advantage.

Lap-welded pipe of the same rated size has always the same outside diameter, whether common, extra, or double extra, but the internal diameter is of course decreased with the increased thickness.

A good cement for steam and water joints is made by taking 10 parts, by weight, of white lead, 3 parts of black oxide of manganese, 1 part of litharge, and mixing them to the proper consistency with boiled linseed oil.

To harden a cutting tool, heat it in a *coke* fire to a blood-red heat and plunge it into a solution of salt and water (1 lb. of salt to 1 gal. of water), then polish the tool, heat it over gas, or otherwise, until a dark straw and purple mixed color shows on the polish, and cool it in the salt water.

Small articles can be plated with brass by dipping them in a solution of $9\frac{1}{4}$ gr. each of sulphate of copper and chloride of tin, in $1\frac{3}{4}$ pt. of water.

Don't be eternally tinkering about your engine, but let well enough alone.

Don't forget that with a copper hammer you can drive a key just as well as with a steel one, and that it doesn't leave any marks.

Keep on hand slips of thin sheet copper, brass, and tin, to use as liners, and if you shape some of them properly, much time will be saved when you need them.

A few wooden skewer pins, such as butchers use, are very useful for many purposes in an engine room. Try them.

In running a line of steam pipe where there are certain rigid points, make arrangements for expansion on the line between those points, or you will come to grief.

Arrange the usual work of the engine and firerooms systematically, and adhere to it. It pays well.

Don't forget that cleanliness is next to godliness.

Rubber cloth kept on hand for joints should be rolled up and laid away by itself, as any oil or grease coming in contact with it will cause it to soften and give out when put to use.

When using a jet condenser, let the engine make three or four revolutions before opening the injection valve, and then open it gradually, letting the engine make several more revolutions before it is opened to the full amount required.

Open the main stop-valve before you start the fires under the boilers.

When starting fires, don't forget to close the gauge-cocks and safety valve as soon as steam begins to form.

An old Turkish towel, cut in two lengthwise, is better than cotton waste for cleaning brass work.

Always connect your steam valves in such a manner that the valve closes against the constant steam pressure.

Turpentine well mixed with black varnish makes a good coating for iron smoke pipes.

Ordinary lubricating oils are not suitable for use in preventing rust.

You can make a hole through glass by covering it with a thin coating of wax, warming the glass and spreading the wax on it. Scrape off the wax where you want the hole, and drop a little fluoric acid on the spot with a wire. The acid will cut a hole through the glass, and you can shape the hole with a copper wire covered with oil and rottenstone.

A mixture of 1 oz. of sulphate of copper, $\frac{1}{4}$ oz. of alum, $\frac{1}{2}$ teaspoonful of powdered salt, 1 gill of vinegar and 20 drops of nitric acid will make a hole in steel that is too hard to cut or file easily. Also, if applied to steel and washed off quickly, it will give the metal a beautiful frosted appearance.

BELTING AND VELOCITY OF PULLEYS.

Belts should not be made tighter than necessary. Over half the trouble from broken pulleys, hot boxes, etc. can be traced to the fault of tight belts, while the machinery wears much more rapidly than when loose belts are employed.

The speed of belts should not be more than 3,000 or 3,750 ft. per minute.

The motion of driving should run with and not against the laps of the belts.

Leather belts should be run with the stronger or flesh side on the outside and the grain (hair) side on the inside, nearest the pulley, so that the stronger part of the belt may be subject to the least wear. It will also drive 30% more than if run with the flesh side nearest the pulley. The grain side adheres better because it is smooth. Do not expose leather belts to the weather.

When the length of a belt cannot be conveniently ascertained by measuring around the pulleys with a tape line, the following rule will be serviceable:

Add the diameters of the 2 pulleys together and divide by 2; multiply this quotient by $3\frac{1}{4}$, and to the product add twice the distance between the centers of the shafts; the sum will be the length required.

COMPRESSED AIR.*

By Prof. Robert Peele.

An air compressor consists essentially of a cylinder in which atmospheric air is compressed by a piston, the driving power being steam or water.

Classification of Compressors.—Steam-driven compressors in ordinary use may be classed as follows:

(*a*) *Straight-line* type, in which a single horizontal air cylinder is set tandem with its steam cylinder, and provided with two flywheels. This pattern is generally adapted for compressors of small size.

(*b*) *Duplex* type, in which there are two steam cylinders, each driving an air cylinder, and coupled at 90° to a crank-shaft carrying a flywheel.

(*c*) *Horizontal, cross-compound* engines, each steam cylinder set tandem with an air cylinder, as in (*b*).

(*d*) *Vertical, simple,* or *compound* engines, with the air cylinders set above the steam cylinders.

(*e*) *Compound* or *stage compressors,* in which the air cylinders themselves are compounded. The compression is carried to a certain point in one cylinder and successively raised and finally completed to the desired pressure in the others. They may be either of the straight-line or duplex form, with simple or compound steam cylinders.

Classes (*a*), (*b*), (*c*), and (*e*) are those commonly employed for mine service. The principle of compound, or two-stage, air compression is recognized as applicable for even the moderate pressures required in mining, and the compressors of class (*e*) are frequently employed.

Construction of Compressors.—Compressors are usually built with a short stroke, as this is conducive to economy in compression as well as the attainment of a proper rotative speed. In ordinary single-stage compressors, the usual ratio of length of stroke to diameter of steam cylinders is $1\frac{1}{5}$ to 1 or $1\frac{1}{4}$ to 1. In some makes, such as the Rand, the ratio is considerably greater, varying from $1\frac{1}{2}$ to $1\frac{2}{3}$ to 1, as in several large plants built for the Calumet & Hecla Mining Co. Many compressors have length and diameter of steam cylinders equal. The relative diameters of the air and steam cylinders depend on the steam pressure carried, and the air pressure to be produced. In mining operations, there is usually but little variation in these conditions. For rock-drill work, the air pressure is generally from 60 to 80 lb.

In using water-power, a compressor is driven most conveniently by a bucket impact wheel, such as the Pelton or Knight. The waterwheel is generally mounted directly on the crank-shaft, without the use of gearing. Since the power developed is uniform throughout the revolution of the wheel, the compressor should be of duplex form, in order to equalize the resistance so far as possible. The rim of the wheel is made extra heavy, to supply the place of a flywheel. When direct-connected, the wheel is of relatively large diameter, as its speed of rotation must of necessity be slow. With small high-speed wheels, the compressor cylinders may be operated through belting or gearing. In most cases, however, the waterwheel may be large enough to render gearing unnecessary. Impact wheels may be employed with quite small heads of water, by introducing multiple nozzles. To prevent the water from splashing over the compressor, the wheel is enclosed in a tight iron or wooden casing. The force of the water is regulated usually by an ordinary gate valve. If the head be great, it may be necessary to introduce means for deflecting the nozzle, so that, when the compressor is to be stopped suddenly, danger of rupturing the water main will be avoided.

Theory of Air Compression.—The *useful effect* or *efficiency* of a compressor is the ratio of the force stored in the compressed air to the work that has been expended in compressing it. This probably never reaches 80%, and often falls below 60%.

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* See "Mines and Minerals," Vols. XIX and XX, for complete discussion of this subject by the same author.

Free air is air at ordinary atmospheric pressure as taken into the compressor cylinder. As commonly used, this means air at sea-level pressure (14.7 lb. per sq. in.) at 60° F.

The *absolute pressure* of air is measured from zero, and is equal to the assumed atmospheric pressure plus gauge pressure. Air-compression calculations depend on the two well-known laws:

1. *Boyle's Law.*—The temperature being constant, the volume varies inversely as the pressure; or $P\ V = P'\ V' =$ a constant; in which V equals volume of given weight of air at the freezing point, and the pressure P; V' equals the volume of the same weight of air at the same temperature and under the pressure P'.

2. *Gay-Lussac's Law.*—The volume of a gas under constant pressure, when heated, expands, for each degree of rise in temperature, by a constant proportional part of the volume that it occupied at the freezing point; or, $V' = V(1 + a\,t^{\circ})$, in which a equals $\frac{1}{273}$ for centigrade degrees, or $\frac{1}{491}$ for Fahrenheit degrees.

Theoretically, air may be compressed in two ways, as follows:

1. *Isothermally*, when the temperature is kept constant during compression, and in this case, the formula $P\ V = P'\ V'$ is true.

2. *Adiabatically*, when the temperature is allowed to rise without check during the compression.

Since the pressure rises faster than the volume diminishes, the equation $P\ V = P'\ V'$ no longer holds, and we have $\frac{P'}{P} = \left(\frac{V}{V'}\right)^n$, in which n equals 1.406. The specific heat of air at constant pressure is .2375, and at constant volume .1689, and $n = \frac{.2375}{.1689} = 1.406$.

In practice, compression is neither isothermal nor adiabatic, but intermediate between the two. The values of n for different conditions in practice are as follows, as determined from a 2,000-horsepower stage compressor at Quai de la Gare, Paris.

For purely adiabatic compression, with no cooling arrangements, $n = 1.406$; in ordinary single-cylinder dry compressors, provided with a water-jacket, n is roughly 1.3; while in the best wet compressors (with spray injection), n becomes 1.2 to 1.25. In the poorest forms of compressor, the value $n = 1.4$ is closely approached. For large, well-designed compressors with compound air cylinders, the exponent n may be as small as 1.15.

Rating of Compressors.—Compressors are rated as follows: (1) In terms of the horsepower developed by the steam end of the compressor, as shown by indicator cards taken when running at full speed, and when the usual volume of air is being consumed. (2) Compressors for mines are often rated roughly as furnishing sufficient air to operate a certain number of rock drills; a 3″ drill requires a volume of air at 60 lb. pressure, equal to 100 or 110 cu. ft. of free atmospheric air per minute. (3) In terms of cubic feet of free air compressed per minute to a given pressure.

As the actual capacity of a compressor depends on the density of the intake air, it will obviously be reduced in working at an altitude above sea level, because of the diminished density of the atmosphere. The following table gives the percentages of output at different elevations:

Altitude. Feet.	Atmospheric Pressure. Pounds.	Percentages of Output at Sea Level.
0	14.7	100.0
1,000	14.2	97.2
2,000	13.6	93.5
3,000	13.1	90.8
4,000	12.7	88.4
5,000	12.2	85.0
6,000	11.7	82.0
7,000	11.3	79.3
8,000	10.9	77.0
9,000	10.5	75.0
10,000	10.1	72.0

EXAMPLE.—Calculate the volume of air furnished by an 18″ × 24″ compressor working at an elevation of 5,000 ft. above sea level, revolving 95 times per minute, and having a piston speed of 380 ft. per minute.

$9^2 \times 3.14 = 254.3$ sq. in. = piston area. $\frac{254.3}{144} \times 380 = 668.8$ cu. ft. = volume displaced per minute by the piston; deducting 10% for loss gives 602 cu. ft. At sea level at 80 lb. gauge pressure, this equals $\frac{15}{80 + 15} \times 602 = 95$ cu. ft. At an elevation of 5,000 ft., the output of a compressor would be $95 \times 85\% = 80.7$ cu. ft. per minute.

Cooling.—Compressor cylinders may be cooled by either of the following methods:

(1) by injecting water into the cylinder, known as *wet* compressors; or (2) by jacketing the cylinder in water, known as *dry* compressors.

Dry Versus Wet Compressors.—Up to about the year 1885 there seemed to be little doubt among mechanical engineers that wet compressors were, on the whole, superior to dry, because, by bringing the air into direct contact with water, the heat is most effectually absorbed. This view is correct, so far as heat loss alone is concerned, provided the water in the cylinder is properly applied. But the question of heat loss is not the only consideration. Low first cost and simplicity of construction are often more advantageous than a close approximation to isothermal compression. Latterly, the wet system has lost ground, owing to the fact that moisture is objectionable in the air, as it forms frost in the exhaust ports of the drills, and stops them up, and probably no wet compressors are now being built in the United States. In Europe, also, dry compressors have grown in favor, at least for mining plants and others of moderate size.

TRANSMISSION OF AIR IN PIPES.

The actual discharge capacity of piping is not proportional to the cross-sectional area alone, that is, to the square of the diameter. Although the periphery is directly proportional to the diameter, the interior surface resistance is much greater in a small pipe than in a large one, because, as the pipe becomes smaller, the ratio of perimeter to area increases.

To pass a given volume of compressed air, a 1″ pipe of given length requires over three times as much head as a 2″ pipe of the same length. The character of the pipe, also, and the condition of its inner surface, have much to do with the friction developed by the flow of air. Besides imperfections in the surface of the metal, the irregularities incident on coupling together the lengths of pipe must increase friction. There are so few reliable data that the influences by which the values of some of the factors may be modified are not fully understood; and, owing to these uncertain conditions, the results obtained from formulas are only approximately correct.

Among the formulas in common use, perhaps the most satisfactory is that of D'Arcy. As adopted for compressed-air transmission, it takes the form:

$$D = c\sqrt{\frac{d^5(p_1 - p_2)}{w_1 l}},$$

in which D = volume of compressed air in cubic feet per minute discharged at final pressure;
c = coefficient varying with diameter of pipe, as determined by experiment;
d = diameter of pipe in inches (the actual diameters of $1\frac{1}{4}''$ and $1\frac{1}{2}''$ pipe are 1.38″ and 1.61″, respectively; the nominal diameters of all other sizes may be taken for calculations);
l = length of pipe in feet;
p_1 = initial gauge pressure in pounds per square inch;
p_2 = final gauge pressure in pounds per square inch;
w_1 = density of air, or its weight in pounds per cubic foot, at initial pressure p_1.

The values of the coefficients c for sizes of piping up to 12″ are:

1″	45.3	5″	59.0	9″	61.0
2″	52.6	6″	59.8	10″	61.2
3″	56.5	7″	60.3	11″	61.8
4″	58.0	8″	60.7	12″	62.0

Some apparent discrepancies exist for sizes larger than 9″, but they cause no very material differences in the results.

Another formula, published by Mr. Frank Richards, is as follows:

$$H = \frac{V^2 L}{10{,}000\, D^5 a},$$

in which H = head or difference of pressure required to overcome friction and maintain the flow of air;
V = volume of compressed air delivered in cubic feet per minute;
L = length of pipe in feet;
D = diameter of pipe in inches;
a = coefficient, depending on the size of pipe.

Values of a for nominal diameters of wrought-iron pipe:

1″	.350	3″	.730	8″	1.125
1¼″	.500	3½″	.787	10″	1.200
1½″	.662	4″	.840	12″	1.260
2″	.565	5″	.934		
2½″	.650	6″	1.000		

The values of a for 1¼″ and 1½″ pipe are not consistent with those for other sizes, for the reason stated above. In using this formula with its constants, the calculated losses of pressure are found to be smaller, and, conversely, the volumes of air discharged are larger, under the same conditions, than those obtained from D'Arcy's formula.

It must be remembered that, within certain limits, the loss of head or pressure increases with the square of the velocity. To obtain the best results, it is found in practice that the velocity of flow in the main air pipes should not exceed 20 or 25 ft. per second. When the initial velocity much exceeds 50 ft. per second, the percentage loss becomes very large; and, conversely, by using piping large enough to keep down the velocity, the friction loss may be almost eliminated. For example, at the Hoosac tunnel, in transmitting 875 cu. ft. of free air per minute, at an initial pressure of 60 lb., through an 8″ pipe, 7,150 ft. long, the average loss including leakage was only 2 lb. A volume of 500 cu. ft. of free air per minute, at 75 lb., can be transmitted through 1,000 ft. of 3″ pipe with a loss of 4.1 lb., while if a 5″ pipe were used the loss would be reduced to .24 lb. The velocity of flow in the latter case is only 10 ft. per second.

In driving the Jeddo mining tunnel, at Ebervale, Pa., two 3¼″ drills were used in each heading, with a 6″ main, the maximum transmission distance being 10,800 ft. This pipe was so large in proportion to the volume of air required for the drills (230 cu. ft. free air per minute) that the loss was reduced to an extremely small quantity. A calculation shows a loss of .002 lb., and the gauges at each end of the main were found to record practically the same pressure.

A due regard for economy in installation, however, must limit the use of very large piping, the cost of which should be considered in relation to the cost of air compression in any given case. Diameters of from 4 to 6 in. for the mains are large enough for any ordinary mining practice. Up to a length of 3,000 ft., a 4″ pipe will carry, per minute, 480 cu. ft. of free air compressed to 82 lb., with a loss of 2 lb. pressure. This volume of air will run four 3″ drills. Under the same conditions, a 6″ pipe, 5,000 ft. long, will carry 1,100 cu. ft. of free air per minute, or enough for 10 drills.

A mistake is often made in putting in branch pipes of too small a diameter. For a distance of, say, 100 ft., a 1¼″ pipe is small enough for a single drill, though a 1″ pipe is frequently used. While it is, of course, admissible to increase the velocity of flow in short branches considerably beyond 20 ft. per second, extremes should be avoided. To run a 3″ drill from a 1″ pipe 100 ft. long, would require a velocity of flow of about 55 ft. per second, causing a loss of 10 lb. pressure.

The piping for conveying compressed air may be of cast or wrought iron. If of wrought iron, as is customary, the lengths are connected either by sleeve couplings or by cast-iron flanges into which the ends of the pipe are screwed or expanded. Sleeve couplings are used for all except the large sizes. The smaller sizes, up to 1¼ in., are butt-welded, while all from 1½ in. up are lap-welded, to insure the necessary strength. Wrought-iron spiral-seam riveted or spiral-weld steel tubing is sometimes used. It is made in lengths of 20 ft., or less. For convenience of transport in remote regions, rolled sheets in short lengths may be had. They are punched around the edges, ready for riveting, and are packed closely—4, 6, or more sheets in a bundle.

All joints in air mains and branches should be carefully made. Air leaks are more expensive than steam leaks because of the losses already suffered in compressing the air. The pipe may be tested from time to time by allowing the air at full pressure to remain in the pipe long enough to observe the gauge. In case a leak is indicated, it should be traced and stopped immediately. In putting together screw joints, care should be taken that none of the white lead or other cementing material is forced into the pipe. This would cause obstruction and increase the friction loss. Also, each length as put in place should be cleaned thoroughly of all foreign substances that may have lodged inside. To render the piping readily accessible for inspection

and stoppage of leaks, it should, if buried, be carried in boxes sunk just below the surface of the ground; or, if underground, it should be supported upon brackets along the sides of the mine workings. Low points in pipe lines, which would form "pockets" for the accumulation of entrained water, should be avoided, as they obstruct the passage of the air. In long pipe lines, where a uniform grade is impracticable, provision may be made near the end for blowing out the water at intervals, when the air is to be used for pumps, hoists, or other stationary engines.

For long lengths of piping, expansion joints are required, particularly when on the surface. They are not often necessary underground, as the temperature is usually nearly constant, except in shafts, or where there may be considerable variations of temperature between summer and winter.

LOSSES IN THE TRANSMISSION OF COMPRESSED AIR.

By E. Hill, Norwalk Iron Works Co.

The increasing use that is being made of compressed-air engines for mine and underground work stimulates the inquiry regarding their efficiency.

The situation is apparently very simple. An engine drives an air compressor, which forces air into a reservoir. The air under pressure is led through pipes to the air engine, and is there used after the manner of steam.

The resulting power is frequently a small percentage of the power expended. In a large number of cases the losses are due to poor designing, and are not chargeable as faults of the system or even to poor workmanship.

The losses are chargeable, first, to friction of the compressor. This will amount ordinarily to 15% or 20%, and can be helped by good workmanship, but cannot probably be reduced below 10%. Second, we have the loss occasioned by pumping the air of the engine room, rather than air drawn from a cooler place. This loss varies with the season, and amounts to from 3% to 10%. This can all be saved. The third loss or series of losses arises in the compressing cylinder. Insufficient supply, difficult discharge, defective cooling arrangements, poor lubrication, and a host of other causes, perplex the designer and rob the owner of power. The fourth loss is found in the pipe. This has heretofore received by no means the consideration that the subject demands. The loss varies with every different situation, and is subject to somewhat complex influences. The fifth loss is chargeable to fall of temperature in the cylinder of the air engine. Losses arising from leaks are often serious, but the remedy is too evident to require demonstration. No leak can be too small to require immediate attention. An attendant who is careless about packings and hose couplings will permit losses for which no amount of engineering skill can compensate.

We can only realize 100% efficiency in the air engine, leaving friction out of our consideration, when the expansion of the air and the changes of its temperature in the expanding or air-engine cylinder are precisely the reverse of the changes that have taken place during the compression of the air in the compressing cylinder. But these conditions can never be realized. The air during compression becomes heated, and during expansion it becomes cold. If the air immediately after compression, before the loss of any heat, was used in an air engine and there perfectly expanded back to atmospheric pressure, it would, on being exhausted, have the same temperature it had before compression, and its efficiency would be 100%.

But the loss of heat after compression and before use cannot be prevented, as the air is exposed to such very large radiating surfaces in the reservoir and pipes, on its passage to the air engine. The heat, which escapes in this way, did, while in the compressing cylinder, add much to the resistance of the air to compression, and since it is sure to escape, at some time, either in reservoir or pipes, it is evidently the best plan to remove it as fast as possible from the cylinder, and thus remove one element of resistance. Hence, we find compressors are almost universally provided with cooling attachments more or less perfect in their action, the aim being to secure isothermal compression, or compression having equal temperature throughout. Where the temperature rises, without check, during compression, the term *adiabatic compression* is employed.

If air compressed isothermally is used with perfect expansion and the fall of temperature during expansion be prevented, then we will have 100% efficiency. But air will grow cold on being expanded in an engine, and hence we conclude that warming attachments have the same economic place on an air engine that cooling attachments have on an air compressor. In fact, we find attachments of this kind more particularly in large and

permanently located engines, but, for practical reasons, their use on most of the engines for mine work is dispensed with, and the engines expand the air adiabatically, or without receiving heat.

The practical engineer, therefore, has to deal with nearly isothermal compression, and nearly adiabatic expansion, and must also consider that the air in reservoirs and pipes becomes of the same temperature as surrounding objects. Consideration must also be had for the friction of the compressor and the air engine. For the pressure of 60 lb., which is that most commonly used, the decrease in resistance to compression secured by the cooling attachments, is almost exactly equaled by the friction of the compressor. Hence it is safe, in calculating the efficiency of the air engine, to consider the compressor as being without cooling attachments, and also as working without friction. The results of such calculations will be too high efficiencies for light pressures, which are little used; about correct for medium pressures, which are commonly employed; and too low for higher pressures, and will thus have the advantage of not being overestimated. This result is occasioned by the fact that, owing to the slight heat in compressing low pressures of air, the saving of power by the cooling attachments is not equal to the friction of the machine, but at high pressures, on account of the great heat, the cooling attachments are of great value and save very much more power than friction consumes.

In the expanding engines, the expansion never falls as low as the adiabatic law would indicate, owing to a number of reasons, but we will consider the expansion as being adiabatic, as an error in calculations caused thereby will be on the "safe side" and the actual power will exceed the calculated power. We therefore consider the compressor and engine as following the adiabatic law of compression and expansion, and as working without friction.

With this view of the case, the efficiency of an air engine, working with perfect expansion, stated in percentages of the power required to operate the compressor, can be placed as below for the various pressures above the atmosphere.

Pressure above the atmosphere, 2.9 lb.	94.85% efficiency.
Pressure above the atmosphere, 14.7 lb.	81.79% efficiency.
Pressure above the atmosphere, 29.4 lb.	72.72% efficiency.
Pressure above the atmosphere, 44.1 lb.	66.90% efficiency.
Pressure above the atmosphere, 58.8 lb.	62.70% efficiency.
Pressure above the atmosphere, 73.5 lb.	59.48% efficiency.
Pressure above the atmosphere, 88.2 lb.	56.88% efficiency.

We observe that the efficiencies for the lower pressures are very much greater than for the high pressures, and the conclusion is almost irresistible that to secure economical results we must design our air engines to run with light pressures. And, in fact, the consideration of tables similar to the above, heretofore published by writers on this subject, has led many engineers into grave errors.

The pipe has been entirely neglected. We notice that a pressure of 2.9 lb. is credited with an efficiency of 94.85%. It is clear that if the air were conveyed through a pipe, and the length of the pipe and the velocity of flow were such that 2.9 lb. pressure was lost in friction, then its efficiency, instead of being 94.85%, would be absolutely zero. It is, therefore, the power that we can get from the air, after it has passed the pipe and lost a part of its pressure by friction, which we must consider when we state the efficiency of our entire apparatus.

Our table of efficiencies with a loss of 2.9 lb. in the pipe, now gives us different values for the efficiencies at the various pressures.

Pressure above the atmosphere, 2.9 lb.	00.00% efficiency.
Pressure above the atmosphere, 14.7 lb.	70.44% efficiency.
Pressure above the atmosphere, 29.4 lb.	68.81% efficiency.
Pressure above the atmosphere, 44.1 lb.	64.87% efficiency.
Pressure above the atmosphere, 58.8 lb.	61.48% efficiency.
Pressure above the atmosphere, 73.5 lb.	58.62% efficiency.
Pressure above the atmosphere, 88.2 lb.	56.23% efficiency.

It will be noticed that the light pressures have lost most by the pipe friction, 2.9 lb. having lost 100%: 14.7 lb. 11%, and 88.2 lb. only a trifle over ½ of 1%. We see that now 14.7 lb. is apparently the economical pressure to use. But a further careful analysis of the subject shows, that when the loss in the pipe is 2.9 lb., then 20.5 lb. is the most economical pressure to use, and that

the efficiency is 71%. But 2.9 lb. is a very small loss between compressor and air engine, and cases are extremely exceptional where the friction of valves, pipes, elbows, ports, etc. does not far exceed this. Yet, with these conditions, which are very difficult to fill, we see that 20.5 lb. is the lightest pressure that should probably ever be used for conveying power, and that 71% is an efficiency scarcely to be obtained.

Continuing our investigation and taking examples where the pipe friction amounts to 5.8 lb., we find the following efficiencies to correspond to the stated pressure:

Pressure above the atmosphere,	14.7 lb.	57.14% efficiency.
Pressure above the atmosphere,	29.4 lb.	64.49% efficiency.
Pressure above the atmosphere,	44.1 lb.	62.71% efficiency.
Pressure above the atmosphere,	58.8 lb.	60.12% efficiency.
Pressure above the atmosphere,	73.5 lb.	57.73% efficiency.
Pressure above the atmosphere,	88.2 lb.	55.59% efficiency.

We again notice that as friction increases, or in other words, when we begin to use more air and make greater demands on the carrying capacity of the pipe, then we must increase pressure very considerably to attain the most economical results. If the demands are such as to increase the friction and loss in pipe to 14.7 lb., the air of 14.7 lb. pressure at the compressor is entirely useless at the air engine.

The table will stand thus:

Pressure above the atmosphere,	14.7 lb.	00.00% efficiency.
Pressure above the atmosphere,	29.4 lb.	48.53% efficiency.
Pressure above the atmosphere,	44.1 lb.	55.13% efficiency.
Pressure above the atmosphere,	58.8 lb.	55.64% efficiency.
Pressure above the atmosphere,	73.5 lb.	54.74% efficiency.
Pressure above the atmosphere,	88.2 lb.	53.44% efficiency.

It is to be noticed that 88.2 lb. pressure has lost only about 3½% of its efficiency by reason of as high a friction as 14.7 lb., while the efficiency of the lower pressures has been greatly affected.

As the friction increases we see that the most efficient, and, consequently, most economical, pressure increases. In fact, for any given friction in a pipe, the pressure at the compressor must not be carried below a certain limit. The following table gives the *lowest pressures* that should be used at the compressor, with varying amounts of friction in the pipe:

2.9 lb. friction.	20.5 lb. at compressor.	70.92% efficiency.
5.8 lb. friction.	29.4 lb. at compressor.	64.49% efficiency.
8.8 lb. friction.	38.2 lb. at compressor.	60.64% efficiency.
11.7 lb. friction.	47.0 lb. at compressor.	57.87% efficiency.
14.7 lb. friction.	52.8 lb. at compressor.	55.73% efficiency.
17.6 lb. friction.	61.7 lb. at compressor.	53.98% efficiency.
20.5 lb. friction.	70.5 lb. at compressor.	52.52% efficiency.
23.5 lb. friction.	76.4 lb. at compressor.	51.26% efficiency.
26.4 lb. friction.	82.3 lb. at compressor.	50.17% efficiency.
29.4 lb. friction.	88.2 lb. at compressor.	49.19% efficiency.

So long as the friction of the pipe equals the amounts given above, an efficiency greater than the corresponding sums stated in the table cannot be expected. If we should have a case that corresponded to any of these cited in the table, we could only increase efficiency by reducing the friction.

An increase in the size of pipe will reduce friction by reason of the lower velocity of flow required for the same amount of air. But many situations will not admit of large pipes being employed, owing to considerations of economy outside of the question of fuel or prime motor capacity.

An increase of pressure will decrease the bulk of air passing the pipe, and in that proportion will decrease its velocity. This will decrease the loss by friction, and, as far as that goes, we have a gain. But we subject ourselves to a new loss, and that is the diminishing efficiencies of increasing pressures. Yet as each cubic foot of air is at a higher pressure, and, therefore, carries more power, we will not need as many cubic feet as before for the same work. It is obvious that with so many sources of gain or loss the question of selecting the proper pressure is not to be decided hastily.

As an illustration of the combined effect of these different elements, we will suppose a very common case.

Compressor 102 revolutions, pressure 52.8 lb., loss in pipe 14.7 lb., machine in mine running at 38.2 lb., efficiency 55.73%.

So long as the friction of the pipe amounts to 14.7 lb., we have seen that 52.8 lb. is the best pressure and 55.73% the greatest efficiency. We will reduce the friction by reducing the bulk of air passing through the pipe. We reduce the cylinder of the air engine so that it requires 47 lb. pressure to do the same work as before. We find now that the friction of pipe drops to 11.7 lb. The pressure on the compressor rises to 58.8 lb., its number of revolutions falls to 100, and the resulting efficiency is 57.22%.

Another change of pressure on compressor to 64.7 lb. would decrease its revolutions to 93, friction to 8.8 lb., and efficiency would rise to 57.94%. Still again increasing the pressure to 73.5 lb., we have only 84 revolutions of compressor, 5.8 lb. loss in pipe, and efficiency of 57.73%. In this last case the efficiency begins to fall off a little, and higher pressures would now show less efficiency; but, in comparison with the first example, we find we are doing the same work in the mine with a trifle less power and with a decrease of nearly 20% in the speed of the compressor.

Other common examples can be shown where an increase of pressure would result in wonderful increase in efficiency and economy. There are many cases where light pressures and high velocity in the pipe will convey a given power with greater economy than higher air pressures and lower speed of flow through the pipe. But these cases arise mostly when the higher air pressures become very much greater than are at present in common use.

Therefore, in estimating the efficiency of the complete outfit, we find that the pipe and the pressure are very important elements, and must be determined with care and skill to secure the most satisfactory results. As the volume and power of air vary with its pressure, the size and consequent cost of compressor for a certain work would also be affected by the pressure. To plan an outfit for a mine, due regard must be had to cost of fuel or prime motor power, and also to cost of compressor, pipes, and machinery, as the saving in one is often secured by a sacrifice in the other.

Next to determining the size of pipe, the skilful engineer has need of further care in the proper position of reservoirs, branches, drains, and other attachments, as only by the exercise of good judgment in this can satisfactory working be secured.

The fact that, on account of the diminished density of the atmosphere at high altitudes, air compressors do not give the same results as at sea level, should also be taken into consideration when a compressor is to be installed in a mountainous region.

Friction of Air in Pipes.—Air in its passage through pipes is subject to friction in the same manner as water or any other fluid. The pressure at the compressor must be greater than at the point of consumption in order to overcome this resistance. The power that is needed to produce the extra pressure representing the friction of the pipe is lost, as there can be no useful return for it. The friction is affected by very many circumstances, but chiefly to be noted is the fact that it increases in direct proportion to the length of the pipe and also as the square of the velocity of the flow of air. The pressure of the air does not affect it.

The losses by friction may be quite serious if the piping system is poorly designed, and, on the other hand, extravagant expenditure in pipe may result from a timid overrating of the evils of friction. A thorough knowledge of the laws governing the whole matter, as well as a ripe experience, is necessary to secure true economy and mechanical success.

The loss of power in pipe friction is not always the most serious result. When a number of machines are in use in a mine, and the pipes are so small as to cause a considerable loss of pressure by friction, then there will be sudden and violent fluctuations in pressure whenever a machine is started or stopped. Breakages will be of common occurrence, as the changes are too quick to be entirely guarded against by the attendant. Perfectly even pressure at the compressor is no safeguard against this class of accidents. The trouble arises in the pipe, and the remedy must be applied there. A system of reservoirs and governing valves will regulate these matters and allow successful work to be done with pipes, which would otherwise be entirely inadmissible.

The ordinary formulas for calculating the volume of air transmitted through a pipe do not take into account the increase of volume due to reduction of pressure, i. e., loss of head. To transmit a given volume of air at a uniform velocity and loss of pressure, it would be necessary to construct the pipe with a gradually increasing area. This, of course, is impracticable,

and in pipe of uniform section both volume and velocity must increase as the pressure is reduced by friction. The loss of head in properly proportioned pipes is so small, however, that in practice the increase in volume is usually neglected.

LOSS OF PRESSURE IN POUNDS PER SQUARE INCH, BY FLOW OF AIR IN PIPES.

Calculated for pipes 1,000 ft. long; for other lengths, the loss varies directly as the length.

Velocity of Air at Entrance to Pipe.		1″ Pipe.			2″ Pipe.			2½″ Pipe.		
Meters per Second.	Feet per Second.	Loss of Pressure. Pounds.	Cubic Feet of Free Air Passed per Minute When Compressed to 60 Lb. Above the Atmosphere.	Cubic Feet of Free Air Passed per Minute When Compressed to 80 Lb. Above the Atmosphere.	Loss of Pressure. Pounds.	Cubic Feet of Free Air Compressed to 60 Lb.	Cubic Feet of Free Air Compressed to 80 Lb.	Loss of Pressure. Pounds.	Cubic Feet of Free Air Compressed to 60 Lb.	Cubic Feet of Free Air Compressed to 80 Lb.
1	3.28	.1435	6	7	.0794	23	29	.0574	32	41
2	6.56	.6405	12	15	.3050	46	59	.2562	65	82
3	9.84	1.4545	18	22	.7216	69	88	.5818	97	124
4	13.12	2.5620	24	29	1.2566	93	117	1.0248	130	165
5	16.40	3.9345	29	37	1.9642	116	146	1.5738	163	207
6	19.68	5.4225	35	44	2.7120	139	175	2.1690	195	247
8	26.24	10.2480	47	59	5.0264	185	234	4.0992	260	330
10	32.80	15.7380	59	74	7.8568	232	294	6.2952	326	413
		3″ Pipe.			4″ Pipe.			5″ Pipe.		
1	3.28	.0463	48	60	.0347	86	109	.0287	134	169
2	6.56	.2092	96	121	.1525	172	217	.1281	268	239
3	9.84	.4880	144	182	.3608	258	326	.2909	402	509
4	13.12	.8381	193	243	.6283	343	436	.5124	537	678
5	16.40	1.3176	241	304	.9821	429	544	.7869	671	844
6	19.68	1.8080	289	364	1.3560	515	653	1.0845	805	1,017
8	26.24	3.3525	386	486	2.5132	687	871	2.0496	1,073	1,357
10	32.80	5.2704	480	607	3.9284	859	1,088	3.1476	1,342	1,696
		6″ Pipe.			8″ Pipe.			10″ Pipe.		
1	3.28	.0232	193	244	.0173	343	434	.0143	537	680
2	6.56	.1046	386	488	.0762	687	864	.0640	1,073	1,359
3	9.84	.2440	579	633	.1805	1,030	1,303	.1455	1,610	2,039
4	13.12	.4190	772	977	.3141	1,373	1,736	.2562	2,146	2,719
5	16.40	.6588	965	1,221	.4910	1,717	2,171	.3934	2,683	3,399
6	19.68	.9040	1,158	1,466	.6780	2,060	2,605	.5423	3,220	4,079
8	26.24	1.6762	1,544	1,954	1.2556	2,747	3,473	1.0248	4,293	5,438
10	32.80	2.6352	1,931	2,443	1.9642	3,434	4,342	1.5738	5,367	6,798

The resistance is not varied by the pressure, only so far as changes in pressure vary the velocity. It increases about as the square of the velocity, and directly as the length.

Elbows, short turns, and leaks in pipes all tend to reduce the pressure in addition to the losses given in the table.

Table of Loss by Friction in Elbows.

An elbow with a radius of one-half the diameter of the pipe is as short as can be made.

Radius of elbow, 5 diams.	Equivalent length of straight pipe, 7.85 diams.
Radius of elbow, 3 diams.	Equivalent length of straight pipe, 8.24 diams.
Radius of elbow, 2 diams.	Equivalent length of straight pipe, 9.03 diams.
Radius of elbow, 1½ diams.	Equivalent length of straight pipe, 10.36 diams.
Radius of elbow, 1¼ diams.	Equivalent length of straight pipe, 12.72 diams.
Radius of elbow, 1 diam.	Equivalent length of straight pipe, 17.51 diams.
Radius of elbow, ¾ diam.	Equivalent length of straight pipe, 35.09 diams.
Radius of elbow, ½ diam.	Equivalent length of straight pipe, 121.20 diams.

ELECTRICITY.

PRACTICAL UNITS.

In electrical work it is necessary to have units in terms of which to express the different quantities entering into calculations. The four most important of these are used to express *strength of current; electrical pressure,* or *electromotive force; resistance; power.*

The **strength of current** flowing in a wire may be measured in several ways. If a compass needle be held under or over a wire, it will be deflected and will tend to stand at right angles to the wire. The stronger the current, the greater the deflection of the needle. If the wire carrying the current be cut and the ends dipped into a solution of silver nitrate, silver will be deposited on the end of the wire toward which the current is flowing, and the amount of silver deposited in a given time will be directly proportional to the average strength of current flowing during that time. When the current flowing in a wire is spoken of, the strength of the current is meant.

Unit Strength of Current.—The unit used to express the strength of a current is called the **ampere.** If a current of 1 ampere be sent through a bath of silver nitrate, .001118 gram of silver will be deposited per second. The expression of the flow of current through a wire as so many amperes is analogous to the expression of the flow of water through a pipe as so many gallons per second.

Electromotive Force.—In order that a current may flow through a wire, there must be an electrical pressure of some kind to cause the flow. In hydraulics, there must always be a head or pressure before water can be made to flow through a pipe. It is also evident that there may be a pressure or head without there being any flow of water, because the opening in the pipe might be closed; the pressure would, however, exist, and, as soon as the valve closing the pipe was opened, the current would flow. In the same way, an electrical pressure or electromotive force (usually written E. M. F.) may exist in a circuit, but no current can flow until the circuit is closed or until the wire is connected so that there will be a path for the current.

Unit Electromotive Force (E. M. F.).—The practical unit of electromotive force is the **volt.** It is the unit of electrical pressure, and fulfils somewhat the same purpose as "pounds per square inch" in hydraulic and steam engineering. The E. M. F. furnished by an ordinary cell of a battery usually varies from .7 to 2 volts. A Daniell cell gives an E. M. F. of 1.072 volts. A pressure of 500 volts is generally used for street-railway work, and, for incandescent lighting, 110 volts is common.

Resistance.—All conductors offer more or less resistance to the flow of a current of electricity, just as water encounters friction in passing through a pipe. The amount of this resistance depends on the length of the wire, the diameter of the wire, and the material of which the wire is composed. The resistance of all metals also increases with the temperature.

Unit of Resistance.—The practical unit of resistance is the **ohm.** A conductor has a resistance of 1 ohm when the pressure required to set up 1 ampere through it is 1 volt. In other words, the *drop*, or fall, in pressure through a resistance of 1 ohm, when a current of 1 ampere is flowing, is 1 volt. 1,000 ft. of copper wire .1 in. in diameter has a resistance of nearly 1 ohm at ordinary temperatures.

Ohm's Law.—The law governing the flow of current in an electric circuit was first stated by Dr. G. S. Ohm, and is known as *Ohm's law.* This law has since stood the test of exhaustive experiment, and has been found correct. Ohm's law may be briefly stated as follows: *The strength of the current in any circuit is directly proportional to the electromotive force in the circuit, and inversely proportional to the resistance of the circuit.*

This means that if the resistance of a circuit were fixed, and the E. M. F. varied, the current would be doubled if the E. M.F. were doubled. Also, if the E. M. F. were fixed, and the resistance doubled, the current would be halved.

Let E = electromotive force in volts;
R = resistance in ohms;
C = current in amperes.

Then, $$C = \frac{E}{R}, \text{ or } R = \frac{E}{C}, \text{ or } E = C\,R.$$

The last two forms are useful in many cases where the usual form $C = \frac{E}{R}$ is not directly applicable.

EXAMPLE.—A dynamo D which generates 110 volts, is connected to a coil of wire C, Fig. 1, which has a resistance of 20 ohms; what current will flow, supposing the resistance of the rest of the circuit to be negligible?

We have E = 110 volts; R = 20 ohms; hence, $C = \frac{110}{20} = 5.5$ amperes.

A problem might also be given as follows: The resistance of the coil C is 6 ohms; what E. M. F. must the dynamo generate in order to set up a current of 15 amperes through it? The third form of the law given above is more convenient in this case.

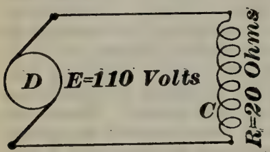


FIG. 1.

$$E = C\,R;\ E = 15 \times 6 = 90 \text{ volts.}$$

In case the current and E. M. F. are known, the resistance of the circuit may be calculated by using the second form of the law given above. For example, if the current in the above case were 8 amperes and the E. M. F. of the dynamo 110 volts, the resistance of the circuit must be

$$R = \frac{E}{C};\ R = \frac{110}{8} = 13.75 \text{ ohms.}$$

Electrical Power.—The electrical power expended in any circuit is found by multiplying the current flowing in the circuit by the pressure required to force the current through the circuit. In other words, $W = E\,C$; where W is the power expended, E is the E. M. F., and C is the current. When E is expressed in volts and C in amperes, then W is expressed in *watts.* The **watt** is the unit of electrical power, and is equal to the power developed when 1 ampere flows under a pressure of 1 volt. The watt is equal to $\frac{1}{746}$ horsepower. We have, then, the following general relations:

Let E = electromotive force in volts;
C = current in amperes;
R = resistance in ohms;
W = power in watts;
H. P. = horsepower.

Then, $W = E\,C$, but $E = C\,R$; hence, $W = C^2\,R$. That is, the power in watts expended in any conductor of which the resistance is R, and through which a current C is flowing, is equal to the product of the squares of the current and the resistance. The energy used in forcing a current through the wire reappears in the form of heat; hence, we may say that the heating effect of a current flowing in a conductor is proportional to the square of the current. From the preceding, we also have

$$\text{H. P.} = \frac{E\,C}{746} = \frac{W}{746}.$$

This relation is very useful for calculating power in terms of electrical units. The watt is too small a unit for convenient use in many cases, so that the kilowatt, or 1,000 watts, is frequently used. This is sometimes abbreviated to K.W.

The Unit of Work Is the Watt-Hour.—This is the total work done when 1 watt is expended for 1 hour. For example, if a current of 1 ampere were made flow for 1 hour through a resistance of 1 ohm, the total amount of work done would be 1 watt-hour. A kilowatt-hour is the total work done when 1 kilowatt is expended for 1 hour. It is about equivalent to $1\frac{1}{3}$ horsepower for 1 hour.

ELECTRICAL EXPRESSIONS AND THEIR EQUIVALENTS.

(*Arranged for Convenient Reference by C. W. Hunt.*)

ONE WATT		A rate of doing work.
	1.	ampere per sec. at one volt.
	.7373	foot-pound per second.
	44.238	foot-pounds per minute.
	2,654.28	foot-pounds per hour.
	.5027	mile-pound per hour.
	.00134	horsepower.
	$\frac{1}{746}$	horsepower.
ONE KILOWATT		A rate of doing work.
	737.3	foot-pounds per second.
	44,238.	foot-pounds per minute.
	502.7	mile-pounds per hour.
	1.34	horsepower.
ONE HORSE-POWER		A rate of doing work.
	550.	foot-pounds per second.
	33,000.	foot-pounds per minute.
	375.	mile-pounds per hour.
	746.	watts.
	.746	kilowatt.
ONE WATT-HOUR		A quantity of work.
	2,654.28	foot-pounds.
	503	mile-pound.
	1.	ampere hour × one volt.
	.00134	horsepower-hour.
	$\frac{1}{746}$	horsepower-hour.
ONE HORSE-POWER-HOUR		A quantity of work.
	1,980,000.	foot-pounds.
	375.	mile-pounds.
	746.	watt-hour.
	.746	kilowatt-hour.
ONE AMPERE-HOUR		A quantity of current.
		One ampere flowing for one hour, irrespective of the voltage.
		Watt-hour ÷ volts.
TORQUE		Force moving in a circle.
		A force of one pound at a radius of one foot.

CIRCUITS.

The path through which a current flows is generally spoken of as an **electric circuit.** This path may be made up of a number of different parts. For example, the line wires may constitute part of the circuit, and the remainder may be composed of lamps, motors, resistances, etc. In practice,

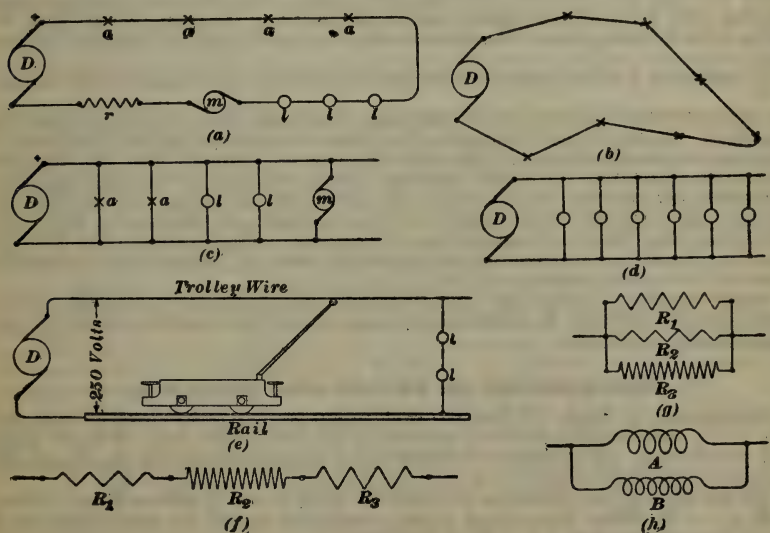


FIG. 2.

the two kinds of circuits most commonly met with are (1) those in which the different parts of the circuit are connected in series; (2) those in which the different parts of the circuit are connected in multiple or parallel.

1. **Series Circuits.**—In this kind of circuit, all the component parts are connected in tandem, so that the current flowing through one part also flows

through the other parts. Fig. 2 (*a*) represents such a circuit made up of a different number of parts. The current leaves the dynamo *D* at the + side and flows through the arc lamps *a a a a*, thence through the incandescent lamps *l l l*, thence through the motor *m* and resistance *r*, back to the dynamo, thus making a complete circuit. All these different parts are here connected in series, so that the current flowing through each of the parts must be the same unless leakage takes place across from one side of the circuit to the other, and this would be impossible if the lines were properly insulated. The pressure furnished by the dynamo must evidently be the sum of the pressures required to force the current through the different parts. The most common use of this system is in connection with arc lamps. These lamps are usually connected in series, as shown in Fig. 2 (*b*). The objections to this system of distribution for general work are that the breaking of the circuit at any point cuts off the current from all parts of the circuit; also, the pressure generated by the dynamo has to be very high if many pieces of apparatus are connected in series. In such a system, the dynamo is provided with an automatic regulator that increases or decreases the *voltage* of the machine, so that the *current* in the circuit is kept constant, no matter how many lamps or other devices are in operation. For this reason, such circuits are often spoken of as *constant-current* circuits.

2. **Parallel Circuits.**—In this type of circuit, the different pieces of apparatus are connected side by side, or in parallel, across the main wires from the dynamo, as shown in Fig. 2 (*c*). In this case, the dynamo *D* supplies current through the mains to the arc lamps *a*, incandescent lamps *l*, and motor *m*. This system is more widely used, and it will be seen at once from the figure that the breaking of the circuit through any one piece of apparatus will not prevent the current from flowing through the other parts. Incandescent lamps are connected in this way almost exclusively. The lamps are connected directly across the mains, as shown in Fig. 2 (*d*). Street cars and mining locomotives are operated in the same way, the trolley wire constituting one main and the track the other, as shown in Fig. 2 (*e*). By adopting this system, any car can move independently of the others, and the current may be turned off and on at will. In all these systems of parallel distribution, the *pressure* generated by the dynamo is maintained constant, no matter what current the dynamo may be delivering. For example, in the lamp system, Fig. 2 (*d*), the dynamo would maintain a constant E. M. F. of 110 volts. Each lamp has a fixed resistance, and will take a certain current $\left(\frac{110}{R} \text{ amperes}\right)$ when connected across the mains. As the lamps are turned on, the current delivered by the dynamo increases, the pressure remaining constant. In street-railway work, the pressure between trolley and track is kept in the neighborhood of 500 volts, the current varying with the number of cars in operation. In mine-haulage plants, the pressure is usually 250 or 500 volts, the former being generally preferred as being less dangerous. Lamps may also be connected in series multiple, as shown in Fig. 2 (*e*). Here the two 125-volt lamps *l l* are connected in series across the 250-volt circuit. Such an arrangement is frequently used in mines when lamps are operated from the haulage circuit.

Such circuits as those just described are called *constant-potential* or *constant-pressure* circuits, to distinguish them from the *constant-current* circuit mentioned previously.

RESISTANCES IN SERIES AND MULTIPLE.

Resistances in Lines.—If two or more resistances are connected in series, Fig. 2 (*f*), their total combined resistance is equal to the sum of their separate resistances. If R equal total combined resistance, and R_1, R_2, R_3 are the separate resistances connected in series, then, $R = R_1 + R_2 + R_3$.

EXAMPLE.—If the separate resistances were $R_1 = 10$ ohms, $R_2 = 1$ ohm, and $R_3 = 30$ ohms, then these three combined would be equivalent to a single resistance of $10 + 1 + 30 = 41$ ohms.

Resistances in Parallel.—If a number of resistances are connected in parallel, the reciprocal of their total combined resistance is equal to the sum of the reciprocals of the separate resistances. In Fig. 2 (*g*), three resistances are shown connected in parallel. It is evident that the total resistance of such a combination must be lower than that of the lowest resistance entering into the combination. If the resistances in this case were all equal,

the resistance of the three combined would be one-third the resistance of one of them, because a current passing through the three combined could split up between three equal paths, instead of having only one path to pass through. If R represents the combined resistance, and R_1, R_2, and R_3 the separate resistances, the following relation is true:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3},$$

from which $$R = \frac{R_1 R_2 R_3}{R_2 R_3 + R_1 R_3 + R_1 R_2}.$$

If the three resistances were all equal, we would have $\frac{1}{R} = \frac{3}{R_1}$, or $R = \frac{R_1}{3}$.

EXAMPLE.—Three resistances of 3, 10, and 5 ohms are connected in parallel. What is their combined resistance? We have

$$\frac{1}{R} = \frac{1}{3} + \frac{1}{10} + \frac{1}{5}, \text{ or } R = \frac{150}{50 + 15 + 30} = \frac{150}{95} = 1.58 \text{ ohms.}$$

Shunt.—When one circuit B, Fig. 2 (h), is connected across another A, so as to form, as it were, a by-pass, or side track, for the current, such a circuit is called a *shunt*, or it is said to be in shunt with the other circuit.

ELECTRIC WIRING (CONDUCTORS).

Materials.—Practically all conductors used in electric lighting or power work are of copper, this metal being used on account of its low resistance. Iron wire is used to some extent for conductors in telegraph lines, and steel is largely used as the return conductor in electric-railway or haulage plants where the current is led back to the power station through the rails. The resistance of iron or steel varies from six to seven times that of copper, depending on the quality of the metal. Aluminum is coming into use as a material for conductors, and in future may play an important part in electric transmission. It is so much lighter than copper that it is able to compete with it as a conductor, even though its cost per pound is higher and its conductivity only about 60% that of copper.

Forms of Conductors.—Most of the conductors used are in the form of copper wire of circular cross-section. Conductors of large cross-section are made up of a number of strands of smaller wire twisted together. For electrolytic plants, copper-refining plants, etc., copper bars of rectangular cross-section are frequently used.

Wire Gauge.—The gauge most generally used in America to designate the different sizes of copper wire is the American, or Brown & Sharpe (B. & S.). The sizes as given by this gauge range from No. 0000, the largest, .460 in. diameter, to No. 40, the finest, .003 in. diameter. Wire drawn to the sizes given by this gauge is always more readily obtained than sizes according to other gauges; hence, in selecting line wire for any purpose it is always desirable, if possible, to give the size required as a wire of the B. & S. gauge. A wire can usually be selected from this gauge, which will be very nearly that required for any specified case.

Estimation of Cross-Section of Wires.—The diameter of round wires is usually given in the tables in decimals of an inch, and the *area of cross-section* is given in terms of a unit called a **circular mil**. This is done simply for convenience in calculation, as it makes calculations of the cross-section much simpler than if the square inch were used as the unit area. A *mil* is $\frac{1}{1000}$ of an inch, or .001 in. A *circular mil* is the area (in decimals of a square inch) of a circle, the diameter of which is $\frac{1}{1000}$ in., or 1 mil. The circular mil is therefore equal to $\frac{\pi}{4}(.001)^2 = .0000007854$ sq. in.

If the diameter of the conductor were 1 in., its area would be .7854 sq. in., and the number of circular mils in its area would be $\frac{.7854}{.0000007854} = 1,000,000$; but 1 in. = 1,000 mils, and $(1,000)^2 = 1,000,000$; hence the following is true: $CM = d^2$; *or the area of cross-section of a wire in circular mils is equal to the square of its diameter expressed in mils.*

EXAMPLE.—A wire has a diameter of .101 in. What is its area in circular mils?

.101 in. = 101 mils. Hence, $CM = (101)^2 = 10,201$.

The following table gives the dimensions, weight, and resistance of pure copper wire. The weights given are, of course, for bare wire. The first column gives the B. & S. gauge number, the second the diameter in mils. The diameter in inches would be the number as given in this column, divided by 1,000. The third column gives the area in circular mils, the numbers in this column being equal to the squares of those in the second column. The safe carrying capacity is also given.

PROPERTIES OF COPPER WIRE. AMERICAN, OR BROWN & SHARPE, GAUGE.

Number. B. & S. Gauge.	Diameter in Mils.	Area in Circular Mils. C. M. = d^2.	Weight. Pounds.		Resistance per 1,000 Ft. International Ohms. 68° F.	Current Capacity (Amperes). National Board Fire Underwriters.	
			Per 1,000 Ft.	Per Mile.		Weather-Proof.	Rubber-Covered.
0000	460.0	211,600.0	640.50	3,381.4	.0489	312	210
000	409.6	167,805.0	508.00	2,682.2	.0617	262	177
00	364.8	133,079.4	402.80	2,126.8	.0778	220	150
0	324.9	105,534.5	319.50	1,686.9	.0981	185	127
1	289.3	83,694.2	253.30	1,337.2	.1237	156	107
2	257.6	66,373.0	200.90	1,060.6	.1560	131	90
3	229.4	52,634.0	159.30	841.1	.1967	110	76
4	204.3	41,742.0	126.40	667.4	.2480	92	65
5	181.9	33,102.0	100.20	529.1	.3128	77	54
6	162.0	26,250.5	79.46	419.5	.3944	65	46
7	144.3	20,816.0	63.02	332.7	.4973		
8	128.5	16,509.0	49.98	263.9	.6271	46	33
9	114.4	13,094.0	39.63	209.2	.7908		
10	101.8	10,381.0	31.43	165.9	.9972	32	24
11	90.7	8,234.0	24.93	131.6	1.257		
12	80.8	6,529.9	19.77	104.4	1.586	23	17
13	71.9	5,178.4	15.68	82.8	1.999		
14	64.1	4,106.8	12.43	76.2	2.521	16	12
15	57.1	3,256.7	9.86	52.0	3.179		
16	50.8	2,582.9	7.82	41.3	4.009	8	6
17	45.2	2,048.2	6.20	32.7	5.055		
18	40.3	1,624.3	4.92	25.9	6.374	5	3
19	35.9	1,288.1	3.90	20.6	8.038		
20	31.9	1,021.5	3.09	16.3	10.14		
21	28.5	810.1	2.45	12.9	12.78		
22	25.3	642.4	1.94	10.3	16.12		
23	22.6	509.4	1.54	8.1	20.32		
24	20.1	404.0	1.22	6.4	25.63		
25	17.9	320.4	.96	5.1	32.31		
26	15.9	254.1	.76	4.0	40.75		
27	14.2	201.5	.61	3.2	51.38		
28	12.6	159.7	.48	2.5	64.79		
29	11.2	126.7	.38	2.0	81.7		
30	10.0	100.5	.30	1.6	103.0		
31	8.93	79.70	.24	1.27	129.9		
32	7.95	63.21	.19	1.01	163.8		
33	7.08	50.13	.15	.801	206.6		
34	6.30	39.75	.12	.635	260.5		
35	5.61	31.52	.095	.504	328.4		
36	5.00	25.00	.075	.400	414.2		
37	4.45	19.83	.060	.317	522.2		
38	3.96	15.72	.047	.251	658.5		
39	3.53	12.47	.038	.199	830.4		
40	3.14	9.89	.030	.158	1,047.0		

The following table gives a comparison of the properties of aluminum and copper:

COMPARISON OF PROPERTIES OF ALUMINUM AND COPPER.

	Aluminum.	Copper.
Conductivity (for equal sizes)	.54 to .63	1
Weight (for equal sizes)	.33	1
Weight (for equal length and resistance)	.48	1
Price (per pound) aluminum, 29 cents; copper, 16 cents (bare wire)	1.81	1
Price (equal length and resistance, bare line wire)	.868	1
Temperature coefficient per degree F.	.002138	.002155
Resistance of mil-foot (20° C.)	18.73	10.5
Specific gravity	2.5 to 2.68	8.89 to 8.93
Breaking strength (equal sizes)	1	1

In case a conductor larger than that given in the table is required, stranded cables are used. These are made in various sizes. The table below gives some of the more common sizes, with their allowable current capacity.

CARRYING CAPACITY OF CABLES.

Area. Circular Mils.	Current. Amperes.		Area. Circular Mils.	Current. Amperes.	
	Exposed.	Concealed.		Exposed.	Concealed.
200,000	299	200	1,200,000	1,147	715
300,000	405	272	1,300,000	1,217	756
400,000	503	336	1,400,000	1,287	796
500,000	595	393	1,500,000	1,356	835
600,000	682	445	1,600,000	1,423	873
700,000	765	494	1,700,000	1,489	910
800,000	846	541	1,800,000	1,554	946
900,000	924	586	1,900,000	1,618	981
1,000,000	1,000	630	2,000,000	1,681	1,015
1,100,000	1,075	673			

Estimation of Resistance.—The resistance of any conductor is directly proportional to its length, and inversely proportional to its area of cross-section, or $R = K\frac{L}{A}$, where K is a constant. If L is expressed in feet and A is expressed in circular mils, then the constant K must be the resistance of a foot of the wire in question of 1 circular mil cross-section. The resistance of 1 mil-foot of copper wire at 75° F. is about 10.8 ohms. Hence, for copper wire, we have $R = \frac{10.8\,L}{A}$; but $A = d^2$ when d is the diameter in mils; hence, we also have $R = \frac{10.8\,L}{d^2}$.

This formula is easily remembered, and is very convenient for estimating the resistance of any length of wire of given diameter when a wire table is not at hand, or when the diameter of the given wire does not correspond to anything given in the table.

EXAMPLE.—Find the resistance of 1 mile of copper wire .20 in. in diameter. 1 mile = 5,280 ft. .20 in. = 200 mils. Area of cross-section = $(200)^2$ = 40,000 circular mils. Hence, $R = \frac{10.8 \times L}{d^2} = \frac{10.8 \times 5{,}280}{40{,}000} = 1.42$ ohms.

CALCULATION OF WIRES FOR ELECTRIC TRANSMISSION.

Direct-Current Circuits.—No matter how large a wire may be, some energy must always be expended in forcing a current through it, because no conductor can be entirely devoid of resistance. It is true that the loss may be made as small as we please by using a very large conductor, but, in practice, this would not pay, because the interest on the cost of the copper would more than counterbalance the gain in the efficiency of transmission. In starting out, then, to estimate the size of wire to transmit a given amount of power over a given distance, one of the first things to be decided is the amount of power that may be allowed for loss in the line, because it is evident that the greater the power lost, the higher may be the line resistance, and hence the smaller the wire. The pressure required to force a current C through a wire of resistance R is $C \times R$. This pressure is generally spoken of as the *drop*, for the reason that the pressure necessary to set up the current through the line is lost, and, consequently, the pressure falls off or drops from the dynamo to the receiving end of the line. In all cases, the pressure at the end of the line, or point where the power is delivered, is equal to the pressure at the dynamo less the drop in the line, and, conversely, the pressure that must be maintained by the dynamo in order to obtain a given pressure at the end will be equal to the pressure at the receiving end plus the drop in the line. To illustrate the above, take the case shown in Fig. 3, where a dynamo D supplies current to a motor M situated 1 mile distant. In order that the motor may operate properly, the pressure at its terminals must be kept constant at, say, 500 volts. It is evident, then, that the pressure between a and b (the dynamo terminals) must be more than 500 volts, by the drop or pressure necessary to force the current through the line. If the motor is taking very little current, i. e., if it is running on a very light load, the current will be small, and hence the drop in the line will be small. In order, then, that the pressure at the motor may remain constant, or nearly so, the pressure at the dynamo must automatically increase as the load increases. The way in which this is done will be explained later; for the present, we are concerned only with the calculation of the line. The line must evidently be designed with regard to the maximum current it has to carry. We will suppose, for the sake of illustration, that the motor takes 50 amperes at full load and that the line wire is of such size that it has a resistance of .2 ohm per mile. The current has to pass through 2 miles of wire (because it has to flow out through 1 mile and back through 1 mile), and hence encounters a resistance of .4 ohm. The *drop* in the line will then be $.4 \times 50 = 20$ volts, and in order to obtain a pressure of 500 volts at the motor, the pressure at the dynamo would have to be 520 volts. The loss of power in the line would be current $\times$ drop $= 50 \times 20 = 1{,}000$ watts, or about $1\frac{1}{3}$ horsepower. The drop in an electrical transmission line is analogous to the loss in pressure due to the friction encountered by water flowing through a pipe line.

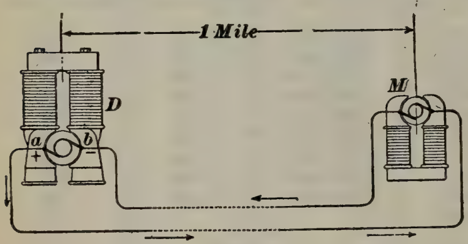


FIG. 3.

If, in the illustration just given, a size of wire were used such that its resistance would be .1 ohm per mile, it is evident that the loss in the line would be halved, but the weight of copper required doubled, because the wire would have to be double the cross-section. The question as to whether it would pay better to invest more money in the line or to put up with the larger loss is something that must be determined in each case by the relative cost of power and copper.

In many cases, the loss allowed in the line is about 10% of the power to be delivered, though sometimes the loss may be allowed to run as high as 15% or 25%. This applies only to transmission lines. For local electric-light or power-distributing systems, the amount of drop allowed is usually about 2% for the former and 5% for the latter.

The problem of calculating line wires usually presents itself in the following form: Given, a certain amount of power to transmit over a known

distance with a certain allowable loss, to determine the cross-section of the wire required.

Let P = power to be delivered, expressed in watts; P will be equal to horsepower delivered at end of line multiplied by 746;
$\%$ = allowable percentage of loss in line, i. e., percentage of *power delivered* that may be lost in transmission;
E = voltage at end of line where power is delivered;
C = current at full load;
L = length of wire through which current flows.

The cross-section of the copper conductor will then be given by the following formula:

$$A = \frac{10.8 \times L \times C \times 100}{E \times \%}. \qquad (1)$$

A will be expressed in circular mils, and the corresponding size of wire may be found by consulting the wire table. It should be noticed, particularly, that in this formula, L is the average length of conductor through which the current C flows. The application of distance of transmission in the formula will be understood from what follows.

EXAMPLE.—A mine pump, driven by an electric motor, is situated 2 miles from the power station. The electrical input of the motor at full load is 50 H. P., and the voltage at its terminals is to be 500. Estimate the size of line wire necessary to supply the motor, the allowable loss in the line being 15% of the power delivered.

The actual length of line through which the current will flow will be 4 miles, because the current has to flow out to the motor and back again. We have

$$C = \frac{\text{watts}}{E} = \frac{50 \times 746}{500} = 74.6 \text{ amperes.}$$

Applying formula (1), we have

$$A = \frac{10.8 \times 2 \times 2 \times 5{,}280 \times 74.6 \times 100}{500 \times 15} = 226{,}880 \text{ circular mils, nearly.}$$

By consulting the wire table it is found that this calls for a wire a little larger than No. 0000, which has a cross-section of 211,600 circular mils; No. 0000 wire would probably be used in this case, as it is near enough to the calculated size for all practical purposes. In case the calculated size comes out larger than any size given in the table, a number of wires may be used in multiple to make up the required cross-section, or, what is better, a stranded cable may be used. These heavy stranded cables may now be obtained in different sizes, up to 2,000,000 circular mils cross-section.

It is evident that, in the above examples, if it were allowable to waste twice as much power in the line, or what is equivalent to having a line drop of 150 volts instead of 75 volts, the cross-section of wire required would have been one-half of that found above. Such a large amount of loss would, however, be objectionable unless power was very cheap. A large drop in the line is in any case objectionable, because the voltage at the receiving end of the circuit will fall off greatly unless the voltage at the generating station is raised, as the load comes on, in order to compensate for the line drop. Most of the uses to which electricity is put, in mines or other places, requires that the pressure at the point where the power is utilized shall be kept approximately constant. For example, in the case of incandescent lights, the lamps will fall off greatly in brightness if the pressure decreases even by a comparatively slight amount. Also, if motors are being operated, the speed will vary considerably if the pressure is not kept constant, and it may be stated, in general, that a large line loss tends to poor regulation at the end of the circuit where power is delivered.

From the above considerations, it will be seen that, in the majority of cases, the size of wire to be used under given conditions is determined by the allowable amount of drop. In some cases, however, especially if the current is to be used near at hand, the size of wire so determined might not be large enough to carry the current without overheating. Of course, in such cases, the safe carrying capacity of the wire determines the size to be used, and the drop will be correspondingly less.

The amount of current that a given wire can carry without overheating depends very largely on the location of the wire. For example, a wire strung in the open air will carry a greater current, with a given temperature rise, than the same wire would if boxed up in a molding or conduit. The

table on page 209 gives the approximate safe carrying capacity of wires when strung in the air.

In order to keep down the size of wire required to transmit a given amount of power over a given distance, with a certain allowable loss, the current must be kept as small as possible. Now, for a given amount of power, the current can only be made small by increasing the pressure, because the number of watts, or power delivered, is equal to the product of the current and the pressure. As a matter of fact, if the pressure in any given case be doubled, the amount of copper required will be only one-fourth as great; in other words, for a given amount of power transmitted, the weight of copper required decreases as the square of the voltage. It is at once seen, then, that if any considerable amount of power is to be transmitted over long distances, a high line pressure must be used or else the cost of copper becomes prohibitory. The use of high pressures in power transmission will be taken up in connection with alternating currents.

Insulated Wires.—For most overhead line work using modern voltages, weather-proof insulated wire is used. This wire is covered with two or three braids of cotton, and treated with insulating compound. For inside work, and in places where a better quality of insulation is required, rubber-covered wires are used. The following table gives the approximate weight of weather-proof line wire. The cost of the wire per pound varies considerably, owing to the variations in the price of copper; about 18 cents per pound may be taken as an approximate figure in making calculations.

WEATHER-PROOF LINE WIRE (ROEBLING'S).

Number. B. & S. Gauge.	Double Braid.			Triple Braid.		
	Outside Diameter. 32ds Inch.	Weight. Pounds.		Outside Diameter. 32ds Inch.	Weight. Pounds.	
		Per 1,000 Ft.	Per Mile.		Per 1,000 Ft.	Per Mile.
0000	20	716	3,781	24	775	4,092
000	18	575	3,036	22	630	3,326
00	17	465	2,455	18	490	2,587
0	16	375	1,980	17	400	2,112
1	15	285	1,505	16	306	1,616
2	14	245	1,294	15	268	1,415
3	13	190	1,003	14	210	1,109
4	11	152	803	12	164	866
5	10	120	634	11	145	766
6	9	98	518	10	112	591
8	8	66	349	9	78	412
10	7	45	238	8	55	290
12	6	30	158	7	35	185
14	5	20	106	6	26	137
16	4	14	74	5	20	106
18	3	10	53	4	16	85

For high-tension lines, it is customary to use bare wires and insulate them thoroughly on special porcelain insulators. The ordinary weather-proof wire insulation is of little or no use as a protection when these high pressures are used, and it only makes the line more dangerous because of the appearance of false security that it gives. In many cases, it is also better to use bare feeders for mine-haulage plants, because the ordinary insulation soon becomes defective in a mine, and a wire in this condition is really more dangerous than a bare wire, because the latter is known to be dangerous and will be left alone.

CURRENT ESTIMATES.

Before calculating the size of wire required for any given case, it is necessary to know the current, and the method of getting at this will depend on what the current is to be used for.

Incandescent Lamps.—These are usually operated on 110-volt circuits, Fig. 4, or on the three-wire system, as shown in Fig. 5. In the three-wire system, two 110-volt dynamos are connected in series so that the voltage across the outside wires is 220. The neutral wire *a a* connects to the point *b* where the machines are connected together. The wire *a a* merely serves to carry the difference in the currents on the two sides of the system, in case more lamps should be burning on one side than on the other. The outside wires for such a system are calculated as if the lights were operated two in series across 220 volts. The middle wire is usually made equal in size to the outer wires. An ordinary 16 c. p. incandescent lamp requires about 55 watts for its operation; a 32 c. p. lamp requires about 110 watts.

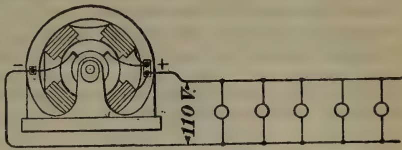


FIG. 4.

Hence, in the case of ordinary parallel distribution, as shown in Fig. 4, the dynamo will deliver about $\frac{1}{2}$ ampere for each 16 c. p. lamp operated, and 1 ampere for each 32 c. p. lamp. In the case of the three-wire system, each pair of 16 c. p. lamps will take $\frac{1}{2}$ ampere, and the total number of amperes in the outside wires will be one-fourth the number of lamps operated.

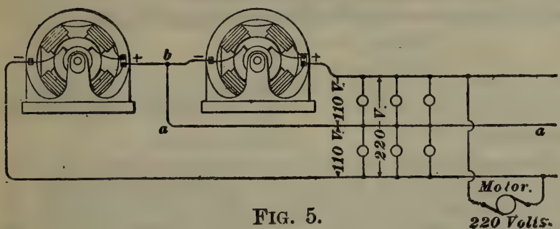


FIG. 5.

EXAMPLE.—A certain part of a mine is to be illuminated by fifty 16 c. p. lamps and ten 32 c. p. lamps. This portion of the mine is 1,000 ft. from the dynamo room, and the allowable drop in pressure is 5%. The lamps are to be run on a 110-volt system. Find the size of wire required.

Fifty 16 c. p. lamps require	25 amperes
Ten 32 c. p. lamps require	10 amperes
Total current	35 amperes

We have, then,

$$\text{circular mils} = \frac{10.8 \times 1{,}000 \times 2 \times 35 \times 100}{110 \times 5} = 137{,}454 \text{ circular mils,}$$

or about a No. 00 B. & S. wire.

EXAMPLE.—Take the same case as in the last example, but suppose the lights to be operated on the three-wire system. There will then be twenty-five 16 c. p. lamps and five 32 c. p. lamps on each side of the circuit, and the total current in the outside wires will be 17.5 amperes. The voltage between the outside wires will be 220, and we will have

$$\text{circular mils} = \frac{10.8 \times 1{,}000 \times 2 \times 17.5 \times 100}{220 \times 5} = 34{,}363 \text{ circular mils,}$$

or about a No. 5 B. & S. wire.

If we make the central wire also of this size, it is seen that this system would require three-eighths the amount of copper called for by the plain 110-volt system. There is the disadvantage that two dynamos are needed.

NOTE.—The length to be used in the wiring formula is the average distance traversed by the current in the conductor. For example, if, as in Fig. 6 (*a*), the lamps were all grouped or bunched at the end of the line, the length used in the formula would be twice that from *G* to *A*, because the whole current has to flow out to *A* through one main and back through the other. In other words, the whole current here passes through the whole length of the line. In case the load is uniformly distributed all along the line, as shown in Fig. 6 (*b*), it is evident that the current decreases step by step from the dynamo to the end. In such a case, the length or distance to be used in the formula is one-half that used in the former case, or simply the distance from the dynamo to the end, instead of twice this distance.

Arc Lamps.—Arc lamps are frequently run on constant-potential circuits, and usually consume from 400 to 500 watts. There are so many types of these lamps that it is difficult to give any current estimates that will be generally applicable. Enclosed arc lamps usually take from 3 to 5 amperes when run on 110-volt circuits.

Motors.—Practically all the motors used in mining work are run on the constant-potential system, either at 250 or 500 volts. The efficiency of ordinary motors will vary from 70% to 95% or higher, depending on the size. The efficiency is greater with the larger machines, and, for the ordinary run of motors, it will probably lie between 80% and 90%. By efficiency is here meant the ratio of the useful output at the pulley or pinion of the motor to the total input. The accompanying table gives the efficiency of motors of ordinary size:

APPROXIMATE MOTOR EFFICIENCY.

$\frac{3}{4}$ to $1\frac{1}{2}$ H. P., inclusive	= 75% efficiency
3 to 5 H. P., inclusive	= 80% efficiency
$7\frac{1}{2}$ to 10 H. P., inclusive	= 85% efficiency
15 H. P. and upwards	= 90% efficiency

If the required output in horsepower is known, the input will be

$$W = \frac{\text{H. P.} \times 746}{\text{efficiency}},$$

and the current required at full load will be $C = \frac{W}{E}$, where E is the voltage between the mains at the motor.

Conductors for Electric-Haulage Plants.—In electric-haulage plants, the rails take the place of one of the conductors, so that, in calculating the size of feeders required, only the overhead conductors are taken into account. It is a difficult matter to assign any definite value to the resistance of the track circuit, as it depends very largely on the quality of the rail bonding at the

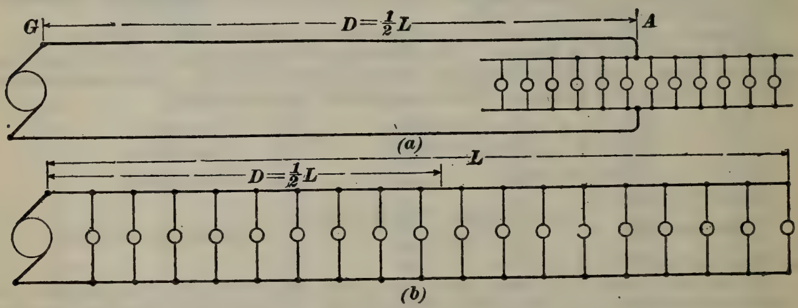


FIG. 6.

joints. If this bonding is well done, the resistance of the return circuit should be very low, because the cross-section of the rails is comparatively large. For calculating the supply feeders, we may use the approximate formula,

$$\text{circular mils} = \frac{14 \times L \times C \times 100}{E \times \% \text{ drop}}.$$

In this case, L is the average length of feeder over which the power is to be transmitted. It will be noticed that the constant 10.8 appearing in the previous formulas has here been increased to 14. This has been done to allow, approximately, for the track resistance, but this constant might vary considerably, depending on the quality of the rail bonding. If the load is all bunched at the end of the feeder, L is the actual length of the feeder in feet. If the load is uniformly distributed all along the line, as it would be if a number of locomotives were continually moving along the line, the distance L in the above formula would be taken as one-half that used in the case where the load was bunched at the end. In other words, the whole current C would only flow through an average of one-half the length of the line.

EXAMPLE.—In Fig. 7, $a\,b$ represents a section of track 4,000 ft. long. From the dynamo c to the beginning of the section, the distance is 1,200 ft. The trolley wire is No. 00 B. & S., and is fed from the feeder at regular intervals. Two mining locomotives are operated, each of which takes an average current of 75 amperes. The total allowable drop to the end of the line is to be 5% of the terminal voltage, which is 500 volts. Calculate the size of feeder required, assuming that the constant 14, in the formula, takes account of the resistance of the return circuit.

Since the locomotives are moving from place to place, the center of distribution for the load may be taken at the center of the 4,000 ft. The

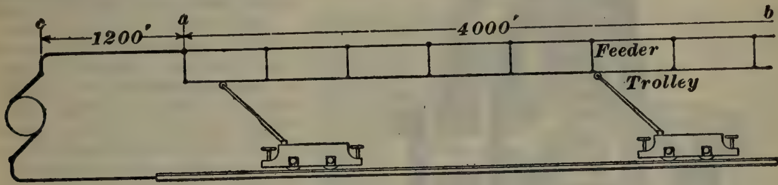


FIG. 7.

distance L will then be $1{,}200 + 2{,}000 = 3{,}200$ ft. The total current will be 150 amperes; hence, we have

$$\text{circular mils} = \frac{14 \times 3{,}200 \times 150 \times 100}{500 \times 5} = 268{,}800.$$

This would require either a stranded cable or the use of two No. 00 wires in parallel from c to a. From a to b we have the No. 00 trolley wire in parallel with the feeder; hence, the section of feeder $a\,b$ may be a single No. 00 wire. In many cases, the drop is allowed to run as high as 10%, because the loads are usually heavier, and the distances longer, than in the example given above.

DYNAMOS AND MOTORS.

A **dynamo** is a machine for converting mechanical energy into electrical energy by moving conductors relatively to a magnetic field.

An **electric motor** is a machine for converting electrical energy into mechanical energy by the relative motion between conductors carrying a current and a magnetic field.

In the case of a dynamo, a number of conductors are made to move across a magnetic field by means of a steam engine or other prime mover, and the result is that an E. M. F. is set up in the conductors, and this E. M. F. will set up a current if the circuit is closed.

In the case of a motor, a number of conductors are arranged so that they are free to move across a magnetic field, and a current is sent through these conductors from some source of electric current. The current flowing through these conductors reacts on the magnetic field and causes the conductors to move, thus converting the electrical energy delivered to the motor into mechanical energy.

As far as mechanical construction goes, dynamos and motors are almost identical, and the operation of the motor is exactly the reverse to that of the dynamo.

Dynamos and motors may be divided into two general classes: (a) Dynamos and motors for *direct current*; (b) dynamos and motors for *alternating current*.

DIRECT-CURRENT DYNAMOS.

Principle of Action.—Direct-current dynamos are those that furnish a current that always flows in the same direction. This kind of dynamo is largely used for incandescent lighting, and also for the operation of street railways.

A dynamo generates an E. M. F. by the motion of conductors across a magnetic field; hence, at the outset, it is seen that there must be at least two essential parts to a dynamo; namely, a magnet of some kind to set up a magnetic field, and a series of conductors arranged so that they may be moved or revolved in the magnetic field. The first part is known as the

field magnet, or very often, simply as the **field.** The second part is known as the **armature.** The field is supplied by means of a powerful electromagnet which is magnetized by the current in the field coils. Fig. 8 shows a typical six-pole magnet of this kind; *B*, *B* are the magnetizing coils, which, when a current is sent through them, form powerful magnetic poles at *N*, *S*. The framework *A* of such a field magnet is usually made of cast iron or cast steel.

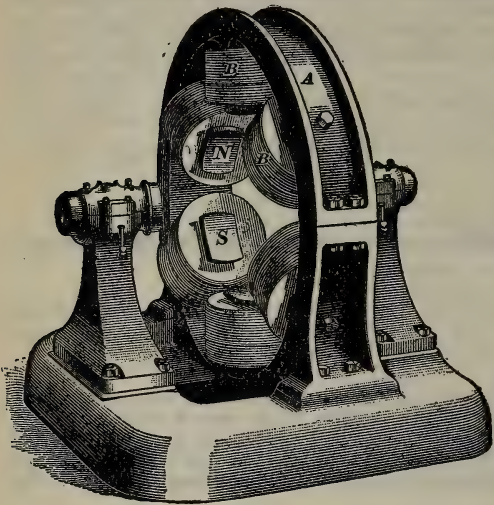


FIG. 8.

These field magnets may have any number of poles, but machines of ordinary size are usually provided with from two to eight poles.

The armature usually consists of a number of turns of insulated copper wire, arranged around the periphery of a ring or drum built up of soft iron sheets. Fig. 9 shows the construction of a typical armature of the ring type. The winding is divided into a number of sections, and the terminals connected to the **commutator.**

This commutator consists of a number of copper bars, insulated from each other by means of mica, the bundle of bars being clamped firmly into place and turned up to form a true cylindrical surface. The sections in the commutator correspond with those in the armature, and the use and operation of the commutator will be described later. The winding on the ring is endless, i. e., it consists of a number of coils or sections *c*, the end of one section being joined to the beginning of the next, thus forming an endless coil, as shown in Fig. 10. The construction of such a ring armature would be as shown in Fig. 9.

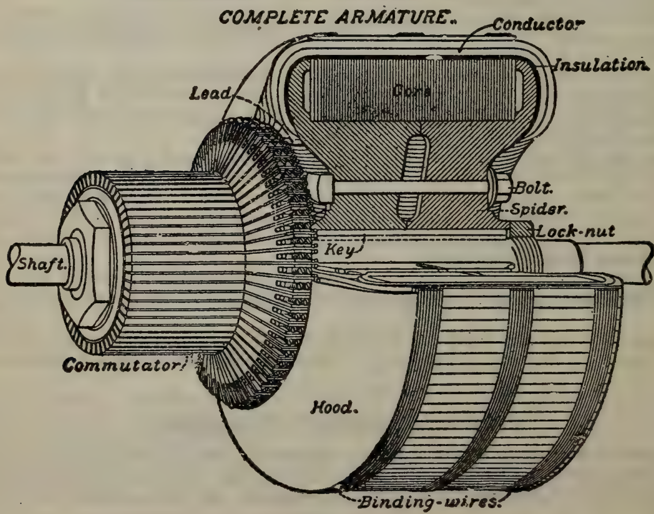


FIG. 9.

Suppose the ring shown in Fig. 10 with its endless winding to be rotated between the poles of a 2-pole field magnet. We will then have the condition of affairs as indicated in Fig. 10. The magnetic lines will flow from the *N* pole of the field magnet across through the iron core of the armature and enter the *S* pole on the other side. Since all the conductors on the right-hand face of the ring are moving upwards, they will have an E. M. F. generated in them in one direction, while the E. M. F. in the conductors on the left side will have an E. M. F. in the opposite direction, because all the conductors on this side are moving downwards, or in the opposite direction, to those on the other side. These two opposing E. M. F.'s will meet at *a*, as shown by the arrowheads, and will neutralize each other so that no current will flow through the windings of the armature. Suppose, however, that taps are connected at the points *a* and *a′*, as shown by the dotted lines, and these taps connected to two rings *r*, *r′*, mounted so as to revolve with the armature. By allowing brushes *b*, *b′* to press on these rings, we can make connection with an outside circuit *d*, which may consist of a number of lamps or any other device through which we wish to send a current. By putting in the taps at *a* and *a′*, we have allowed the two opposing E. M. F.'s to set up a current through the common connections to the rings, and thence through the outside circuit. Current now flows in each half of the armature winding, unites at *a*, flows out by means of ring *r′* and brush *b′*, thence through the outside circuit *d* to brush *b* and ring *r*, from whence it passes to *a′*, and thus completes the circuit. When the ring makes a half revolution from the position shown in the figure, it is seen that the current in the ouside circuit will flow in the opposite direction. In fact, an arrangement of this kind would deliver a current that would be periodically reversing in the outside circuit, or it would be what is known as an *alternating current*.

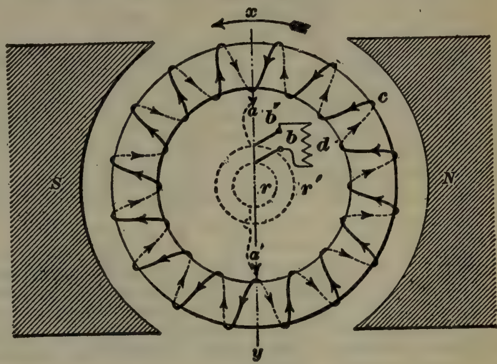


FIG. 10.

Instead of simply bringing out two terminals to rings, suppose the winding to be tapped at a fairly large number of points, and connections brought down to a number of insulated strips, as shown in Fig. 11. If the armature be now revolved, it is seen that the brushes will come in contact with successive bars and keep the outside circuit in such relation to the armature winding that the current will always flow through it in the same direction. Moreover, if the number of divisions in the armature be large, the current will fluctuate very little, being nearly as steady as that obtained from a battery. The arrangement made up of insulated bars is called the commutator, because it commutes or changes the relation of the outside circuit to the armature winding so that the current in the outside circuit always flows in the same direction. All practical machines used for the generation of direct current must be provided with such a commutator. When alternating currents are used it is only necessary to use plain collector rings, as

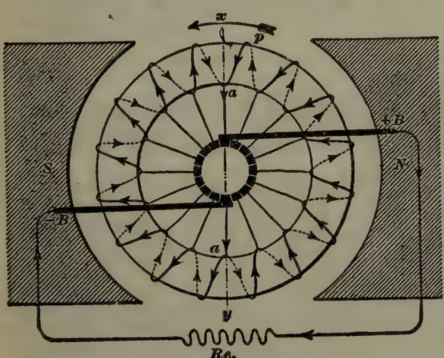


FIG. 11.

shown in Fig. 10. The foregoing brief description will give a general idea as to the construction of an ordinary direct-current dynamo or motor. Drum-wound armatures are more frequently used than the ring type shown, but the action is the same in either case.

Factors Determining E. M. F. Generated.—A dynamo should be looked upon as a machine for maintaining an electrical pressure rather than as a machine for generating a current. A pump does not manufacture water—it merely maintains a head or pressure that causes water to flow wherever an outlet is provided for it to flow through. In the same way, a dynamo maintains a pressure, and this pressure will set up a current whenever the circuit is closed, so that the current can flow. The important thing to consider, therefore, is the E. M. F. that the dynamo is capable of generating.

The E. M. F. generated by an armature depends on the total number of magnetic lines cut through per second by the armature conductors. This means that, in the first place, the faster the armature runs, the higher will be the E. M. F.; in the second place, the greater number of conductors or turns there are on the armature, the higher will be the E. M. F.; and in the third place, the stronger the magnetic field, the higher will be the E. M. F. The E. M. F. in terms of these quantities may be written

$$E = \frac{n\,C\,N}{100{,}000{,}000},$$

where n = speed in revolutions per second;
C = number of conductors on face of the armature;
N = number of magnetic lines flowing from one pole.

The constant 100,000,000 is necessary to reduce the result to volts. This equation enables us to make calculations relating to any two-pole dynamo, and with slight modification it is applicable to machines with field magnets

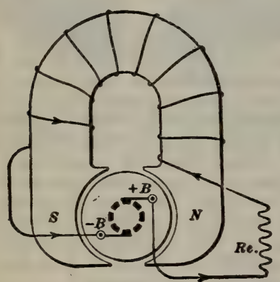


FIG. 12.

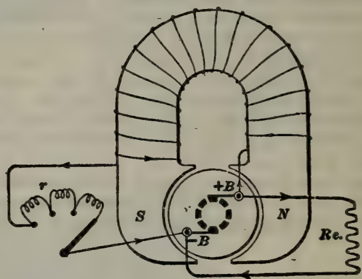


FIG. 13.

having a number of poles. It will not be necessary to consider this formula further here, as the main thing to fix in mind is that the E. M. F. is proportional to the three quantities: speed, number of conductors, and strength of field.

Field Excitation of Dynamos.—In the earliest form of dynamo, the magnetic field in which the armature rotated was set up by means of permanent magnets. Permanent magnets are, however, very weak compared with electromagnets, which are excited by means of current flowing around coils of wire wound on a soft-iron core, as shown in Fig. 13. As soon as the current ceases flowing around the coils of an electromagnet, the magnetism almost wholly disappears, but a small amount, known as the *residual magnetism* remains. It is to this residual magnetism that the dynamo owes its ability to start up of its own accord and excite its own field magnets. When the armature is first started to revolve, a very feeble E. M. F. is generated in it, but the armature is connected to the field coils in such a way that this small E. M. F. is able to force a small current through the field coils, and thus set up a larger amount of magnetism in the field. This in turn increases the E. M. F. in the armature, and the building-up process goes on rapidly until the dynamo generates its full pressure. There are three different methods in use for supplying the field coils with current, and continuous-current dynamos are divided into three classes, according to the method used for exciting their fields. These three classes are: (a) Series-wound dynamos; (b) shunt-wound dynamos; (c) compound-wound dynamos.

(*a*) **Series-Wound Dynamos.**—In this class of machine, the field coils are connected in series with the armature, and all the current that passes through the armature also passes through the field and the outside circuit. This arrangement is shown in Fig. 12, where *N* and *S* represent the poles of the magnet, $+B$ and $-B$ the brushes, and *Re* the outside circuit, which may consist of lamps, motors, or any other device in which it is desired to utilize the current. It will be noticed that with an arrangement of this kind, the E. M. F. will increase as the current increases, because the field will become stronger and the speed is supposed to remain constant. This will be true up to the point where the field carries all the magnetism it is capable of, or, in other words, until it becomes saturated. After this point is reached, the E. M. F. will increase very little with increase of current. In most of the work connected with lighting or power transmission, it is desirable to have the voltage remain nearly constant. For this reason, therefore, the series method of excitation has not been very largely used for dynamos. The only style of generator to which it has been applied at all generally is the arc-light dynamo, and these machines are provided with an automatic regulator of some kind to vary the voltage as desired. The series field winding has, however, been largely used in connection with the motors operated on constant-pressure circuits, as will be taken up later in connection with motors.

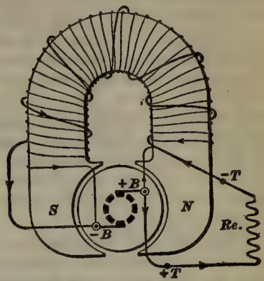


FIG. 14.

(*b*) **Shunt-Wound Dynamos.**—This style of machine has not been used largely of late years, although it was formerly very common. Its use is at present confined more particularly to machines of small size. In this method of excitation, the field is connected as a shunt or by-pass to the armature; i. e., the field winding is connected in parallel with the armature. This winding consists of a large number of turns of fine wire, so that its resistance is high and only a small part of the total current flows through it. Fig. 13 shows the connections for this kind of field excitation. An adjustable resistance *r* is usually inserted in the field circuit, and by cutting this resistance in or out, the field may be weakened or strengthened and the voltage varied accordingly. With this type of machine, the current through the field does not vary greatly from no load to full load, and if the dynamo is well designed, the pressure at the brushes will keep approximately constant. The pressure will, however, always fall off more or less, on account of the drop in the armature, due to its resistance, and also upon the tendency that the current in the armature has of weakening the field. The shunt winding is used quite largely for motors.

(*c*) **Compound-Wound Dynamos.**—The compound-wound dynamo is the one most largely used for direct-current power and light distribution, and it is so called because the winding used for exciting the field is a combination of the series and shunt windings previously described. The series winding serves the purpose of keeping up the field strength while the load is increased, and thus keeps the pressure constant, or even makes it rise with increased load, if so desired. When the series winding is so adjusted that the pressure rises as the load is increased, the machine is said to be *overcompounded*. Fig. 14 shows the connections for such a machine. It will be seen that the shunt winding is connected as before, a field resistance or rheostat, not shown in the figure, being inserted for the purpose of adjusting the voltage. One brush connects directly to one terminal of the machine $+T$, while the other brush connects to one end of the series winding on the field. The other end of the series winding forms the other terminal $-T$, to which the outside circuit *R e* is connected. It is thus seen that the shunt coil supplies a certain amount of initial magnetization that is augmented by the magnetism supplied by the series coils. Of course, care must be taken to see that the current in the series coils circulates around the field in the same direction as that in the shunt coils, otherwise the effect would be to make the E. M. F. fall off with increasing load instead of keeping it up. This is the style of dynamo used almost exclusively for electric haulage plants, as well as plants for direct-current illuminating purposes.

DIRECT-CURRENT MOTORS.

Direct-current motors are in general almost identical, so far as construction goes, with direct-current dynamos. Motors are often required to operate under very trying conditions, as for example, in mine haulage or pumping plants or on the ordinary street car. For this reason, their mechanical construction often differs somewhat from that of the dynamo, the design being modified in such a way as to enclose the working parts as completely as possible, and thus protect them from dirt and injury. The two kinds of motors most commonly used are the series and shunt varieties. Compound-wound motors are only used for a few special kinds of work. Practically all of the motors in use are operated from constant-pressure mains; i. e., the pressure at the terminals of the motor is practically constant, no matter what load it may be carrying. We will here consider constant-potential motors only.

Principles of Operation.—If the fields of an ordinary constant-potential dynamo are excited and a current supplied to the armature from some outside source, such as another dynamo *D*, Fig. 15, so that the current enters at $+B$, and passing through the winding in the direction indicated by the arrowheads, leaves at brush $-B$, it will be found that all of the conductors under the *S* pole face, *b*, *c*, *d*, *e*, *f*, and *g*, will tend to move *downwards*, and all those under the *N* pole face, *j*, *k*, *l*, *m*, *n*, and *o*, will tend to move *upwards*, as indicated by the small arrows.

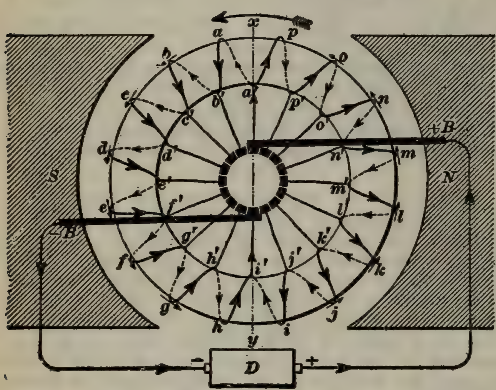


FIG. 15.

These forces combine to produce a tendency of the armature to rotate about its axis as indicated by the large arrows, which tendency is called the **torque** of the motor.

The amount of this torque—which is usually expressed in pound-feet; that is, a certain number of pounds acting at a radius of a certain number (usually 1) of feet—depends on (1) the strength of the field, (2) the number of conductors, (3) their mean distance from the axis of the armature, and (4) the amperes in each conductor. In any given machine, the second and third conditions are constant, so that the torque depends on the strength of the field and the current.

If the armature is stationary, the E. M. F. required to send the current through the winding is only that necessary to overcome the drop, which is due to the resistance of the winding. If the torque exerted by this current is greater than the opposition to motion, so that it causes the armature to revolve, the motion of the conductors through the field generates in them an E. M. F. that is *opposed to the E. M. F. that is sending the current through the armature.*

This opposing E. M. F., or *counter E. M. F.* as it is called, then diminishes the effect of the applied E. M. F., so that the current is reduced, reducing the torque. Should the torque still be greater than the opposition to motion, the speed of the armature will continue to increase, increasing the counter E. M. F., and thereby further reducing the current and the corresponding torque, *until the torque just balances the opposition to the motion,* when the speed will remain constant.

At all times, the drop of potential through the armature is equal to the *difference between the counter and the applied E. M. F.'s*, and as the product of this drop and the current represents energy wasted, it is desirable to make it as low as possible. In good motors of about 10 H. P. output, the drop in the armature is seldom more than about 5% of the applied E. M. F., and is less in larger machines.

This being the case, it is evident that if the armature is at rest, so that it

has no counter E. M. F., and is connected directly to the mains, a very large current will flow through it, which would be liable to damage the armature. On this account an external resistance, called a *starting resistance*, is connected in series with the armature when it is to be started. This resistance is made great enough to prevent more than about the normal current from flowing through the armature when it is at rest; as the armature speeds up and develops some counter E. M. F., this resistance is gradually cut out, until the armature is connected directly to the mains, and is running at normal speed.

The energy represented by the product of drop in the armature and the current is wasted; that represented by the product of the current and the rest of the E. M. F., that is, the counter E. M. F., is the energy required to keep the armature in motion.

Aside from the comparatively small amount of current required to furnish the torque necessary for overcoming the frictional losses in the motor itself, which are practically constant, the amount of current taken from the mains is directly proportional to, and varies automatically with, the amount of the external load; for, if this external load is increased, the current which has been flowing in the armature cannot furnish sufficient torque for this increased load, so that the machine slows down. This decreases the counter E. M. F., which immediately allows more current to flow through the armature, increasing the torque to the proper amount. If the external load is decreased, the current flowing furnishes an excess of torque, which causes the speed to increase, increasing the counter E. M. F., and decreasing the current until it again furnishes only the required amount of torque.

Since the counter E. M. F. is very nearly equal to the applied, it is only necessary for it to vary a small amount to vary the current within wide limits. For example, if the resistance of a certain armature is 1 ohm, and it is supplied with current at a constant potential of 250 volts, then, when a current of 10 amperes is flowing through it, the drop is $10 \times 1 = 10$ volts, and the counter E. M. F. is $250 - 10 = 240$ volts. Now, if the current is reduced to 1 ampere, the drop is $1 \times 1 = 1$ volt, and the counter E. M. F. is $250 - 1 = 249$ volts; that is, the counter E. M. F. only varies $\frac{9}{240}$, or 3.75%, while the current varies $\frac{9}{10}$, or 90%.

As stated before, the field magnets of constant-potential motors are usually either shunt-wound or series-wound.

If shunt-wound, and supplied from a constant-potential circuit, the magnetizing force of the field coils is constant, giving a practically constant field. This being the case, the counter E. M. F. is directly proportional to the speed, so that variations of the load make only slight variation in the speed. A shunt-wound motor is then (practically) a *constant-speed* motor.

With series-wound motors, the strength of the field varies with the current; if the load on such a motor is reduced, the excess of torque makes the armature speed up, but as the resulting decrease of the current decreases the field strength, the armature must speed up to a much greater extent, in order to increase the counter E. M. F. to the right degree, than would be necessary if the field were constant. If the load is increased, the increase in the current so increases the field strength that the speed must decrease considerably, in order to decrease the counter E. M. F. by the right amount. The speed of a series-wound motor, then, varies largely with variations in the load.

An advantage of the series motor is that if a torque greater than the normal is required, it can be obtained with less current than with a shunt motor, since the increased current increases the field strength, and the torque is proportional to both these factors.

It would not be practicable to make the field strength of a shunt motor as great as is possible to get with a series motor, since it would require a very large magnetizing force, and with the shunt winding, this extra magnetizing force would have to be expended all the time, whether the strong field was required or not, which would be very wasteful; in the series motor, however, this extra magnetizing force is only expended while it is needed.

A disadvantage of the series winding is that if all the load is taken off, the current required to drive the motor is very small, making a weak field, which requires such a high speed to generate the proper counter E. M. F. that the armature is liable to be damaged. In other words, the motor will *race*, or *run away*, if the load is all removed. This cannot occur with the shunt motor as long as the field circuit remains unbroken.

On account of the above features, shunt motors are used to drive machinery that requires a nearly constant speed with varying loads, or which would be damaged if the speed should become excessive, such as ordinary machinery in shops and factories, pumps, etc. Series motors are used on street cars, to operate hoists, etc., where, on account of the gearing used, the load cannot be entirely thrown off, and the torque required at starting and getting quickly up to speed is much greater than the normal amount.

Speed Regulation of Motors.—The *torque* of a motor depends on the current; that is, for a given current, the torque will be the same whatever may be the speed, provided the field strength remains the same. The *speed* at which the armature runs is a matter of E. M. F. only; that is, with a given current the speed will be proportional to the applied E. M. F., or, more strictly, the counter E. M. F., other conditions remaining the same.

It has been shown that the torque will automatically regulate itself for changes in the load. The speed, however, may be varied by varying the applied E. M. F. or the strength of the field. A change in speed may or may not result in a change in the torque required, depending on the character of the work done by the motor.

The simplest way to vary the applied E. M. F. is to insert a resistance in series with the armature, similar to the starting resistance. By varying this resistance, the applied E. M. F. at the terminals of the motor is also varied, although the E. M. F. of the mains remains constant. It is evident

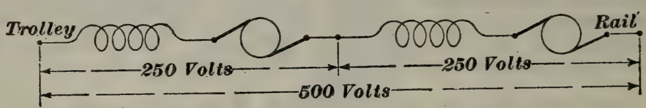


FIG. 16.

that the energy represented by the product of the current and the drop through the resistance is converted into heat, and is thereby wasted; therefore, for great variations in speed, this method is not economical, though often very convenient.

The applied E. M. F. may also be varied by varying the E. M. F. of the generator supplying the current, but this can only be done where a single generator is supplying a single motor, or several motors, whose speed must all be varied at the same time; so that this method is only used in special cases.

If the strength of the field is changed, the speed necessary to give a certain counter E. M. F. will also be changed, which gives a convenient method of varying the speed. If the strength of the field is lessened, the speed will increase, and if the field is strengthened, the speed will decrease. With shunt motors, the field may be weakened by inserting a suitable resistance in the field circuit, as in shunt dynamos; with series motors the same result may be obtained by cutting out some of the turns of the field coils or by placing a suitable resistance in parallel with the field coils.

This method of regulation is also of limited range, since it is not economical to maintain the strength of the field much above or below a certain density. The resistance method described above being rather more simple, it is generally used. For special cases, such as street-railroad work, various special combinations of the above methods of regulation are used.

One of the most common of these is known as the **series-parallel method**, and is the method of regulation generally used at present for operating street cars. This method is equivalent to the method of cutting down the speed by reducing the E. M. F. applied to the motor, and is only applicable where at least two motors are used. It is also used, to some extent, in haulage plants. When a low speed is desired, or when the car is to be started up, the motors are thrown in series, as shown in Fig. 16, thus making the voltage across each motor equal to one-half the voltage between the lines, and cutting down the speed accordingly. When a high speed is

desired, the motors are thrown in multiple, as shown in Fig. 17, and each motor runs at full speed because it gets the full line pressure. In practice, starting resistances are used in connection with the above to make the starting smooth, but the two running positions are as shown, the motors being connected in series in the one case, and in parallel in the other.

Connections for Continuous-Current Motors.—Fig. 18 shows the manner in which a shunt motor is connected to the terminals + and − of the circuit. It will be seen that the current through the shunt field does not pass through the resistance R which is connected in the armature circuit. This is necessary, since to keep the field strength constant, the full difference of potential must be maintained between the terminals of the field coil, which would not be the case if the rheostat were included in the field current, for then the difference of potential would be only that existing between the brushes $+B$ and $-B$. As on starting the motor this difference of potential is small, only a small current would flow through the field coils, which would generate such a weak field that an excessive current would be required to furnish the necessary torque for starting the motor.

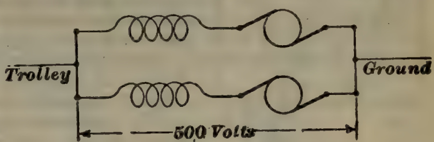


FIG. 17.

When connected as shown, however, the field is brought up to its full strength before any current passes through the armature; so this difficulty does not arise.

Since in a series motor the same current flows through both armature and field coils, the starting resistance may be placed in any part of the circuit. The diagram in Fig. 19 illustrates one method of connecting a series motor to the line terminals + and −; here the starting or regulating resistance R is placed between the − line terminal and the brush $-B$ of the motor.

To reverse the direction of rotation of a motor it is necessary to reverse *either* the direction of the field or the direction of the current through the armature. It is usual to reverse the direction of the current in the armature, a switch being used to make the necessary changes in the connections.

Fig. 20 shows the connections of one form of reversing switch. Two metal bars B and B_1 are pivoted at the points T and T_1; one is extended and supplied with a handle H, and the two bars are joined together by a link L of some insulating material, such as fiber. Three contact pieces a, b, and c are arranged on the base of the switch so that the free ends of the

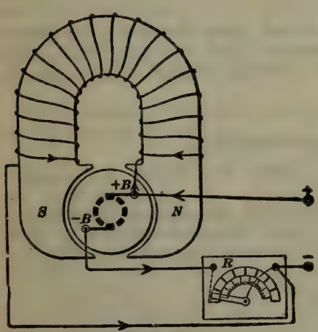


FIG. 18.

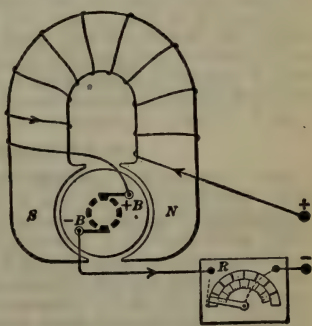


FIG. 19.

bars B and B_1 may rest either on a and b, as shown by the full lines, or on b and c, as shown by the dotted lines. The line is connected to the terminals T and T_1, and the motor armature between a and b, or vice versa, a and c being connected together.

When the switch is in the position shown by the full lines, T is connected to a by the bar B, and T_1 to b by the bar B_1. If the switch is thrown by means of the handle H into the position indicated by the dotted lines, T is connected to b by the bar B, and T_1 to a by the bar B_1 and the connection

between c and a. The direction of the current through the motor armature, or whatever circuit is connected between a and b, is thus reversed.

In order to reverse only the current in the armature, the reversing switch must be placed in the armature circuit only. Fig. 21 represents the connection for a reversing-shunt motor (a) and a reversing-series motor (b); + and — are the line terminals; R, the starting resistance; B and B_1, the brushes of the motor, and F, the field coil of the motor. Some manufacturers combine the starting resistance and reversing switch in one piece of apparatus.

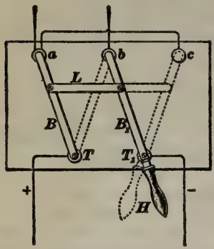


FIG. 20.

In connecting up motors, some form of main switch is used to entirely disconnect the motor from the line when it is not in use.

To prevent an excessive current from flowing through the motor circuit from any cause, short strips of an easily melted metal, known as **fuses,** mounted on suitable terminals, known as **fuse boxes,** are placed in the circuit. These fuses are made of such a sectional area that a current greater than the normal heats them to such an extent that they melt, thereby breaking the circuit and preventing damage to the motor from an excessive current. The length of fuse should be proportioned to the voltage of the circuit, a high voltage requiring longer fuses than a low voltage, in order to prevent an arc being maintained across the terminals when the fuse melts.

If desired, measuring instruments (ammeter and voltmeter) may be connected in the motor circuit, so that the condition of the load on the motor may be observed while it is in operation. All these appliances, regulating resistance, reversing switch, fuses, instruments, etc., are placed

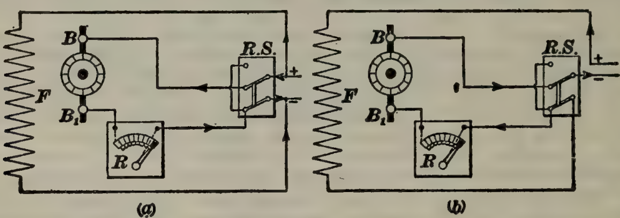


FIG. 21.

inside the main switch; that is, the current must pass through the main switch before coming to any of these appliances, so that opening the main switch entirely disconnects them from the circuit, when they may be handled without fear of shocks.

ALTERNATING-CURRENT DYNAMOS.

An alternating-current dynamo is one that generates a current that periodically reverses its direction of flow. It was shown in connection with Fig. 10 that an armature provided simply with collector rings produced an alternating current in the outside circuit. This current may be represented by a curve such as that shown in Fig. 22. The complete set of values that the current or E. M. F. passes through repeatedly is known as a **cycle.** For example, the values passed through during the interval of time represented by the distance $a\,c$ would constitute a cycle. The set of values passed through during the interval $a\,b$ is known as an alternation. An alternation is, therefore, half a cycle. The number of cycles passed through per second is known as the *frequency* of the current, or E. M. F.

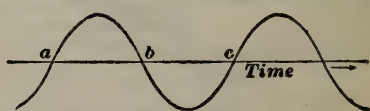


FIG. 22.

Alternating-current dynamos are now largely used both for lighting and power transmission, especially when the transmission is over long distances. The reason that the alternating current is specially suitable for long-distance

work is that it may be readily transformed from one pressure to another. We have already seen that in order to keep down the amount of copper in the line, a high line pressure must be used. Pressures much over 500 or 600 volts cannot be readily generated with direct-current machines, owing to the troubles that are likely to arise due to sparking at the commutator. On the other hand, an alternator requires no commutator or even collecting rings, if the armature is made stationary and the field revolving, as is frequently done. Alternators are now built that generate as high as 8,000 or 10,000 volts directly. If a still higher pressure is required on the line, it can be easily obtained by the use of transformers, to be explained later. It is thus seen that where power is to be carried over long distances, the alternating current is indispensable.

Alternating-current dynamos, like direct-current machines, consist of two main parts, i. e., the field and armature. Either of these parts may be the revolving member, and in many modern machines the armature, or the part in which the current is induced, is the revolving member. Fig. 23 shows a typical alternator of the belt-driven type, having a revolving armature. It is not unlike a direct-current machine as regards its general appearance. The number of poles is usually large, in order to secure the required frequency without running the machine at a high rate of speed. The frequencies met with in practice vary all the way from 25 to 150. The higher frequencies are, however, passing out of use, and at present a frequency of 60 is very common. This frequency is well adapted both for power and lighting purposes. When machines are used almost entirely for lighting work, frequencies of 125 or higher may be used. The frequency of any machine may be readily determined when the number of poles and the speed is known, as follows:

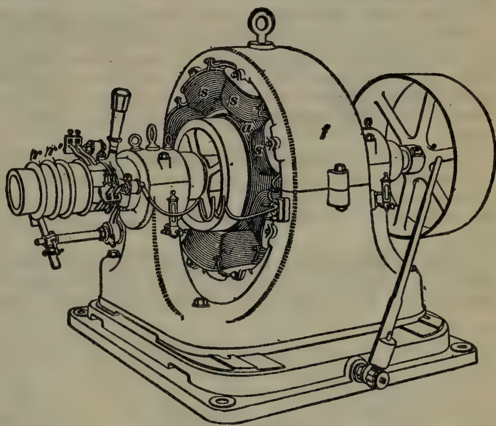


FIG. 23.

$$\text{Frequency} = \frac{\text{number of poles}}{2} \times \frac{\text{rev. per min.}}{60}.$$

For example, if an eight-pole alternator were run at a speed of 900 R. P. M., the frequency would be

$$f = \frac{8}{2} \times \frac{900}{60} = 60 \text{ cycles per second.}$$

Alternators may be divided into the two following classes: (*a*) Single-phase alternators; (*b*) Multiphase alternators.

(*a*) **Single-Phase Alternators.**—These machines are so called because they generate a single alternating current (as represented by the curve shown in Fig. 22). The armature is provided with a single winding and the two terminals are brought out to collector rings, as previously described. Single-phase machines have been largely used in the past for lighting work, but they are gradually being replaced by multiphase machines, because the single-phase machines are not well suited for the operation of alternating-current motors.

(*b*) **Multiphase Alternators.**—These machines are so called because they deliver two or more alternating currents that differ in phase; i. e., when one current is, say, at its maximum value, the other currents are at some other value. This is accomplished by providing the armature with two or more distinct windings which are displaced relatively to each other on the armature. One set of windings, therefore, comes under the poles at a later instant than the winding ahead of it, and the current in its winding comes

to its maximum value at a later instant than the current in the first winding. In practice, the two types of multiphase alternator most commonly used are (1) two-phase alternators, (2) three-phase alternators.

Two-phase alternators are machines that deliver two alternating currents that differ in phase by one-quarter of a complete cycle; i. e., when the current in one circuit is at its maximum value, the current in the other circuit is passing through its zero value. By tapping four equidistant points of a regular ring armature, as shown in Fig. 24, and connecting these points to four collector rings, a simple two-pole two-phase alternator is obtained. One circuit connects to rings *1* and *1'*, the other circuit connects to rings *2* and *2'*. It is easily seen from the figure that when the part of the winding connected to one pair of rings is in its position of maximum action, the E. M. F. in the other coils is zero, thus giving two currents in the two different circuits that differ in phase by one-quarter of a cycle or one-half an alternation.

Three-phase alternators are machines that deliver three currents that differ in phase by one-third of a complete cycle; i. e., when one current is flowing in one direction in one circuit, the currents in the other two circuits are one-half as great, and are flowing in the opposite direction. By tapping three equidistant points of a ring winding, as shown in Fig. 25, a simple three-phase two-pole alternator is obtained. Three mains lead from the collecting rings.

In order to have three distinct circuits, it would ordinarily be necessary to have six collecting rings and six circuits; but this is not necessary in a three-phase machine if the load is balanced in the three different circuits, because one wire can be made to act alternately for the return of the other two.

Uses of Multiphase Alternators.—Multiphase alternators are coming largely into use, because, by using them, alternating-current motors can be readily operated. By using multiphase machines, motors can be operated that will

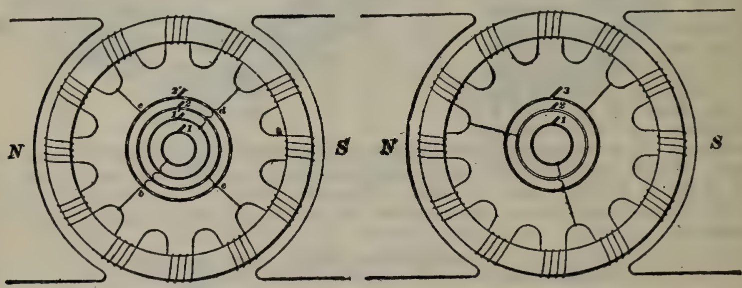


FIG. 24. FIG. 25.

start from rest under load, whereas with single-phase machines the motor has to be brought up to speed from some outside source of power before it can be made to run. For this reason, such machines are used for the operation of modern power-transmission plants. As far as the general appearance of three-phase machines goes, they are similar to ordinary single-phase alternators, the only difference being in the armature winding and the larger number of collector rings. The multiphase alternator is also adapted for the operation of lights, so that by using these machines, both lights and motors may be operated from the same plant. They are well adapted for power-transmission purposes in mines, especially for the operation of pumping and hoisting machinery, because the motors operated by them are very simple in construction and therefore not liable to get out of order.

ALTERNATING-CURRENT MOTORS.

Alternating-current motors may be divided into two general classes: (*a*) Synchronous motors; (*b*) Induction motors.

(*a*) **Synchronous motors** are almost identical, so far as construction goes, with the corresponding alternator. For example, a two-phase synchronous motor would be constructed in the same way as a two-phase alternator.

They are called synchronous motors because they always run in synchronism, or in step, with the alternator driving them. This means that the motor runs at the same frequency as the alternator, and if the motor had the same number of poles as the alternator, it would run at the same speed, no matter what load it might be carrying. This type of motor has many good points, and is especially well suited to cases where the amounts of power to be transmitted are comparatively large and where the motor does not have to be started and stopped frequently. Multiphase synchronous motors will start up from rest and will run up to synchronous speed without aid from any outside source. They will not, however, start with a strong starting torque or effort, and will not, therefore, start up under load, and cannot be used in places where a strong starting effort is required. For this reason synchronous motors are not suitable for intermittent work.

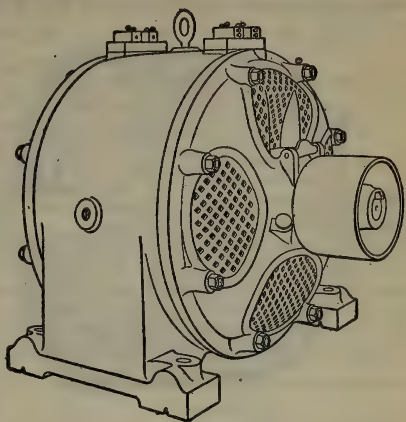


FIG. 26.

(*b*) **Induction motors** are so called because the current is induced in the armature instead of being led into it from some outside source. Fig. 26 shows a typical induction motor. There are two essential parts in these machines, viz., the *field*, into which multiphase currents are led from the line, and the armature, in which currents are induced by the magnetism set up by the field. Either of these parts may be the stationary or revolving member, but in most cases the field, or part that is connected to the line, is stationary. Fig. 27 shows the construction of the stationary member or field. This consists of a number of iron laminations, built up to form a core and provided with slots around the inner periphery. The form-wound coils constituting the field winding are placed in these slots and connected to the mains. This winding is arranged in the same way as the armature winding of a multiphase alternator. When the alternating currents differing in phase are sent through the winding, magnetic poles are formed at equidistant points around the periphery of the field, and the constant changing of the currents causes these poles to shift around the ring, thus setting up what is known as a revolving magnetic field. This armature, Fig. 28, consists of a laminated iron core provided with a number of slots, in each of which is placed a heavy copper bar *b*. The ends of these bars are all connected together by two heavy short-circuiting rings *r*, *r* running around each end of the armature. The bars and end rings thus form a number of closed circuits. When such an armature is placed in the revolving field. the magnetism will cut across the armature conductors, inducing E. M. F.'s in them, and since the conductors are joined up into closed circuits, currents will flow in them. These currents will react on the field, and the armature will be forced to revolve. Such an armature will not run exactly in synchronism, because if it did, it would revolve just as fast as the magnetic field, and there would be no cutting of

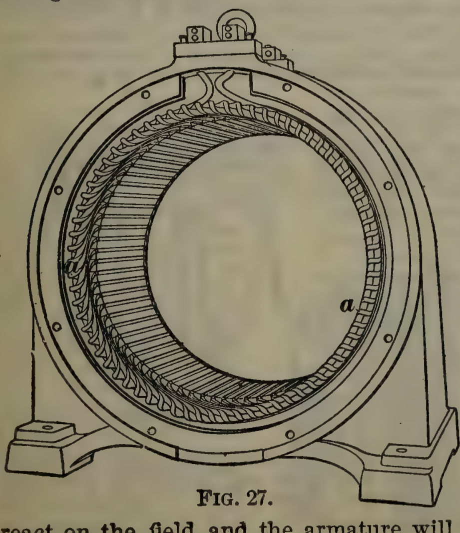


FIG. 27.

lines of force. The speed drops slightly from no load to full load, but if the motor is well designed, this falling off in speed is slight.

Induction motors possess many advantages for mine work. One of the chief of these is the absence of the commutator or any kind of sliding contacts whatever. Such motors can therefore operate with absolutely no sparking—a desirable feature for mine work. The motors are also very simple in construction, and are therefore not liable to get out of order. They have an additional advantage over the synchronous motor in that they start up with a strong starting effort, and, in fact, behave in most respects like any good shunt-wound direct-current motor. They are used quite successfully for all kinds of stationary work, such as pumping, hoisting, etc., but so far have not been used to any great extent for haulage purposes. When these motors are used for purposes where a variable speed is required, it is customary to provide the armature with a winding similar to that of the field and bring out the terminals to collecting rings, so that resistance may be inserted in the armature circuit.

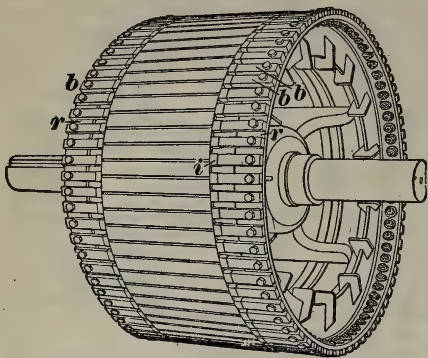


FIG. 28.

TRANSFORMERS.

Reference has already been made to the use of transformers for changing an alternating current from a higher to a lower pressure, or vice versa, with a corresponding change in current. Transformers used for raising the voltage are known as *step-up* transformers; those used for lowering the pressure are known as *step-down* transformers.

The transformer consists of a laminated iron core upon which two coils of wire are wound. These coils are entirely distinct, having no connection with each other. One of these coils, called the *primary*, is connected to the mains; the other coil, called the *secondary*, is connected to the circuit to which current is delivered. Fig. 29 shows the arrangement of coils and core for a common type of transformer. The secondary coil is wound in two parts S, S', and the primary coil, also in two parts P, P', is placed over the secondary. C is the core, built up of thin iron plates. Fig. 30 shows a weather-proof cast-iron case for this transformer. When a current is sent through the primary it sets up a magnetism in the core which rapidly alternates with the changes in the current. This changing magnetism sets up an alternating E. M. F. in the secondary, and this secondary E. M. F. depends upon the number of turns in the secondary coil. If the secondary turns are greater than the primary, the secondary E. M. F. will be higher than that of the primary. The relation between the primary E. M. F. and secondary E. M. F. is given by the following:

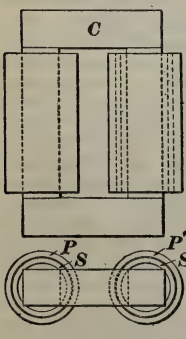


FIG. 29.

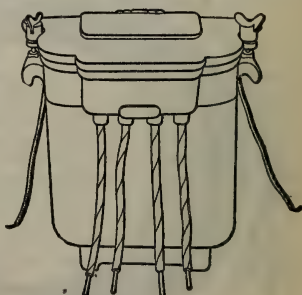


FIG. 30.

$$\text{Secondary E. M. F.} = \text{primary E. M. F.} \times \frac{\text{secondary turns}}{\text{primary turns}}.$$

or, $$\text{secondary E. M. F.} = \frac{\text{primary E. M. F.}}{\dfrac{\text{primary turns}}{\text{secondary turns}}}.$$

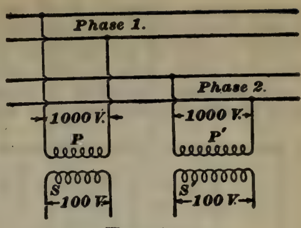


FIG. 32.

The ratio $\dfrac{\text{primary turns}}{\text{secondary turns}}$ is known as the ratio of transformation of the transformer. For example, if a transformer had 1,200 primary turns and 60 secondary turns, its ratio of transformation would be 20 to 1, and the secondary voltage would be one-twentieth that of the primary. Transformers are made for a number of different ratios of transformation, the more common ones being 10 to 1 or 20 to 1. Of course, a transformer never gives out quite as much power from the secondary as it takes in from the primary mains, because there is always some loss in the iron core and in the wire making up the coils. The efficiency

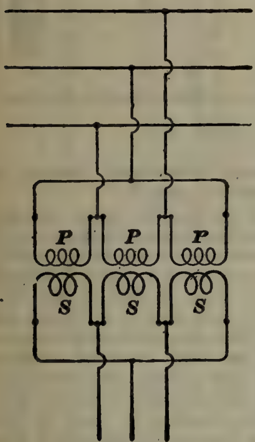


FIG. 33.

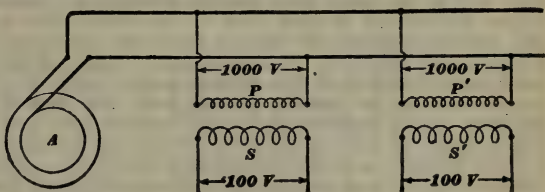


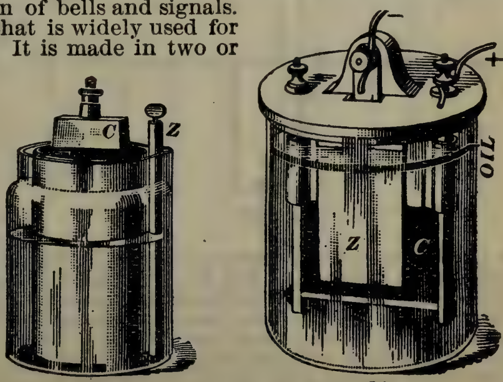
FIG. 31.

of transformers is, however, high, reaching as high as 97% or 98% in the larger sizes. Transformers are always connected in parallel across the mains, and if they are well designed, will furnish a very nearly constant secondary pressure at all loads, when furnished with a constant primary pressure. Fig. 31 shows transformers connected on a single-phase circuit, Fig. 32 shows the connection for a two-phase circuit, and Fig. 33 shows one method of connection for a three-phase circuit.

ELECTRIC SIGNALING.

BATTERIES.

Batteries are used for various purposes in connection with mining work, principally for the operation of bells and signals. The *Leclanché* cell is one that is widely used for bell and telephone work. It is made in two or three different forms, one of the most common of these being as shown in Fig. 34 (*a*). The zinc element of this battery is in the form of a rod *Z*, and weighs about 3 oz. The other electrode is a carbon plate placed in a porous cup and surrounded with black oxide of manganese, mixed with crushed coke or carbon. The electrolyte used in the battery is a saturated solution of sal



(*a*) (*b*)

FIG. 34.

ammoniac. The E. M. F. of this cell is about 1.48 volts when the cell is in good condition. In another form of the cell, known as the *Gonda* type, the black oxide of manganese is pressed into the form of bricks and clamped against each side of the carbon plate by means of rubber bands. This cell will do good work if it is only used intermittently, i. e., on circuits where the insulation is good and where there is no leakage causing the cell to give

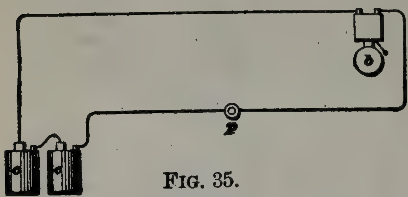


FIG. 35.

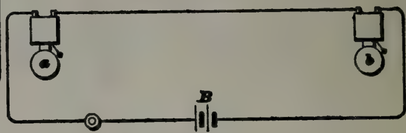


FIG. 36.

out current continuously. If current is taken from it for any length of time, it soon runs down, but will recuperate if allowed to stand.

In cases where the insulation is apt to be poor, as it often is in mines, it is best to use a battery that will stand a continuous delivery of current and that will at the same time operate all right on intermittent work or on work where the circuit is open most of the time. For work of this kind, cells of the *Edison-Lalande* or *Gordon* type are excellent. Fig. 34 (*b*) shows the Edison-Lalande cell. The elements consist of two zinc plates *Z*, hung on each side of a plate of compressed cupric oxide *C*. The electrolyte is a saturated solution of caustic potash, and this should be kept covered with a layer of heavy paraffin oil, to prevent the action of the air on the solution. The voltage of the cell is only .7 volt, but its internal resistance is very low and its current capacity correspondingly large. The electrolyte used in the Gordon cell is also caustic-potash solution, and the two cells are much the same, so far as their general characteristics are concerned. The table on page 231 gives data relating to a number of different types of cell.

BELL WIRING.

The **simple bell** circuit is shown in Fig. 35, where *p* is the push button, *b* the bell, and *c*, *c* the cells of the battery connected up in series. When two or more bells are to be rung from one push button, they may be joined up

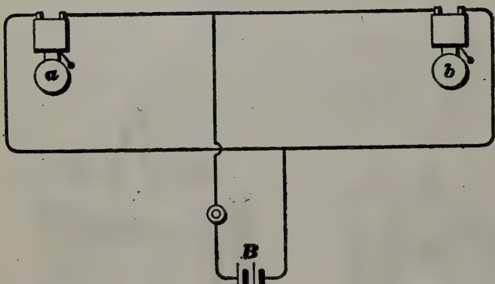


FIG. 37.

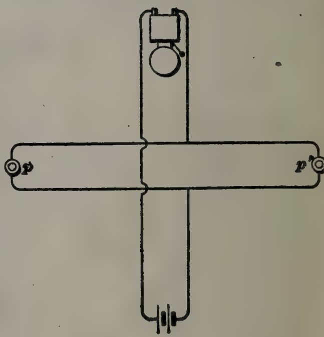


FIG. 38.

in parallel across the battery wires, as in Fig. 37 at *a* and *b*, or they may be arranged in series, as in Fig. 36. The battery *B* is indicated in each diagram by short parallel lines, this being the conventional method. In the parallel arrangement of the bells, they are independent of each other, and the failure of one to ring would not affect the others; but in the series grouping, all but one bell must be changed to a single-stroke action, so that each impulse of current will produce only one movement of the hammer. The current is then interrupted by the vibrator in the remaining bell, the result

Name.	Anode.	Electrolyte.	Cathode.	Depolarizer.	E. M. F.	Remarks.
Volta	Zinc	Sulphuric acid (dilute)	Copper	None	.9	Polarizes rapidly.
Law	Zinc	Sulphuric acid (dilute)	Carbon	None	1.35	
	Zinc	Sodium chloride (common salt)	Carbon	None	1.08	
Grenet	Zinc	Sulphuric acid 4 Potassium bichromate 3 Water 18	Carbon	Electrolyte	1.9 to 2	For large currents.
Pabst	Wrought iron	Ferric chloride	Carbon		.78	Non-polarizing electrolyte.
Bunsen	Zinc	Sulphuric acid (dilute)	Carbon	Nitric acid	1.89	Cathode and depolarizer in porous cup.
Fuller	Amalgamated zinc in mercury	Sulphuric acid (very dilute) or water	Carbon	Electropoion fluid diluted one-half	2.14	Anode in porous cup.
Partz	Zinc	Sodium chloride or magnesium sulphate	Carbon	Bichromate solution (sulphochromic salt)	1.9 to 2	Gravity cell. Resistance with sodium chloride, .5 ohm; with magnesium sulphate, 1 ohm.
D'Arsonval	Zinc	Caustic soda	Carbon	Ferric chloride	2.7	Porous cup used; pores become filled with ferric hydrate, an insoluble conductor.
Daniell	Zinc	Zinc sulphate	Copper	Copper sulphate with copper-sulphate crystals	1.07	Cathode and depolarizer in porous cup.
Gravity Daniell	Zinc	Zinc sulphate. Sp. Gr. 1.10	Copper	Copper sulphate with copper-sulphate crystals	1.07	For closed-circuit work only; resistance 3 ohms.
Leclanché	Zinc	Ammonium chloride (saturated)	Carbon	Peroxide of manganese	1.48	Carbon and depolarizer in porous cup; resistance 4 ohms.
Lalande and Chaperon	Zinc	Caustic potash	Iron or Copper.	Cupric oxide	.7	Surface of electrolyte covered with layer of oil.
Edison-Lalande	Zinc	Caustic potash	Molded plates of cupric oxide and magnesic chloride held in copper frames		.7	Surface of electrolyte covered with layer of oil; resistance .07 ohm.
Chloride-of-mercury cell	Zinc	Sal ammoniac (ammonium chloride)	Carbon	Paste of mercurous chloride.	1.45	Cathode and depolarizer in porous cups. For small currents.
Gordon	Zinc	Caustic soda	Flaky copper oxide in perforated copper cylinder		.7	For open or closed circuit working.

being that each bell will ring with full power. The only change necessary to produce this effect is to cut out the circuit-breaker on all but one bell by connecting the ends of the magnet wires directly to the bell terminals.

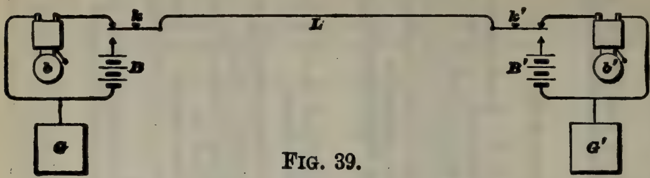


FIG. 39.

FIG. 40.

When it is desired to ring a bell from one of two places some distance apart, the wires may be run as shown in Fig. 38. The pushes p, p' are located at the required points, and the battery and bell are put in series with each other across the wires joining the pushes.

A single wire may be used to ring signal bells at each end of a line, the connections being given in Fig. 39. Two batteries are required, B and B', and a key and bell at each station. The keys k, k' are of the double-contact type, making connections normally between bell b or b' and line wire L. When one key, as k, is depressed, a current from B flows along the wire through the upper contact of k' to bell b' and back through ground plates G', G.

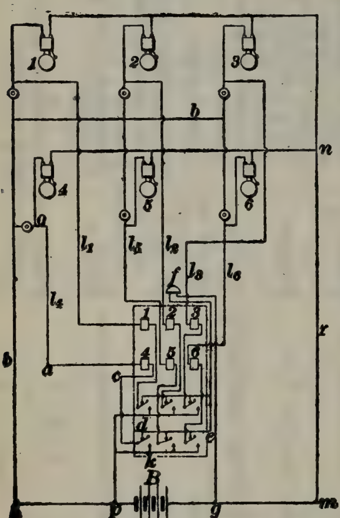


FIG. 41.

When a bell is intended for use as an alarm apparatus, a constant-ringing attachment may be introduced, which closes the bell circuit through an extra wire as soon as the trip at door or window is disturbed. In the diagram, Fig. 40, the main circuit, when the push p is depressed, is through the automatic drop d by way of the terminals a, b to the bell and battery. This current releases a pivoted arm which, on falling, completes the circuit between b and c, establishing a new path for the current by way of e, independent of the push p.

For operating electric bells, any good type of open-circuit battery may be used. The Leclanché cell is largely used for this purpose, also several types of dry cells.

Annunciator System.—The wiring diagram for a simple annunciator system is shown in Fig. 42. The pushes *1*, *2*, *3*, etc. are located in various places, one side being connected to the battery wire b, and the other to the leading wire l in communication with the annunciator drop corresponding to that place. A battery of two or three Leclanché cells is placed at B in any convenient location. The size of wire used throughout may be No. 18 annunciator wire.

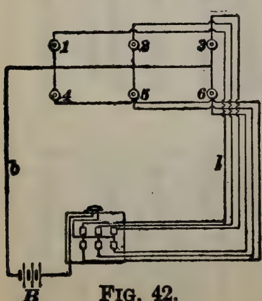


FIG. 42.

A **return-call** system is illustrated in Fig. 41, in which there is one battery wire b, one return wire r, and one leading wire l, l_2, etc. for each place. The upper portion of the annunciator board is provided with the usual drops, and below these are the return-call pushes. These are double-contact buttons, held normally against the upper contact by a spring. When in this

position, the closing of the circuit by the push button in any room, such as No. 4, rings the office bell and releases No. 4 drop, the path of the current in

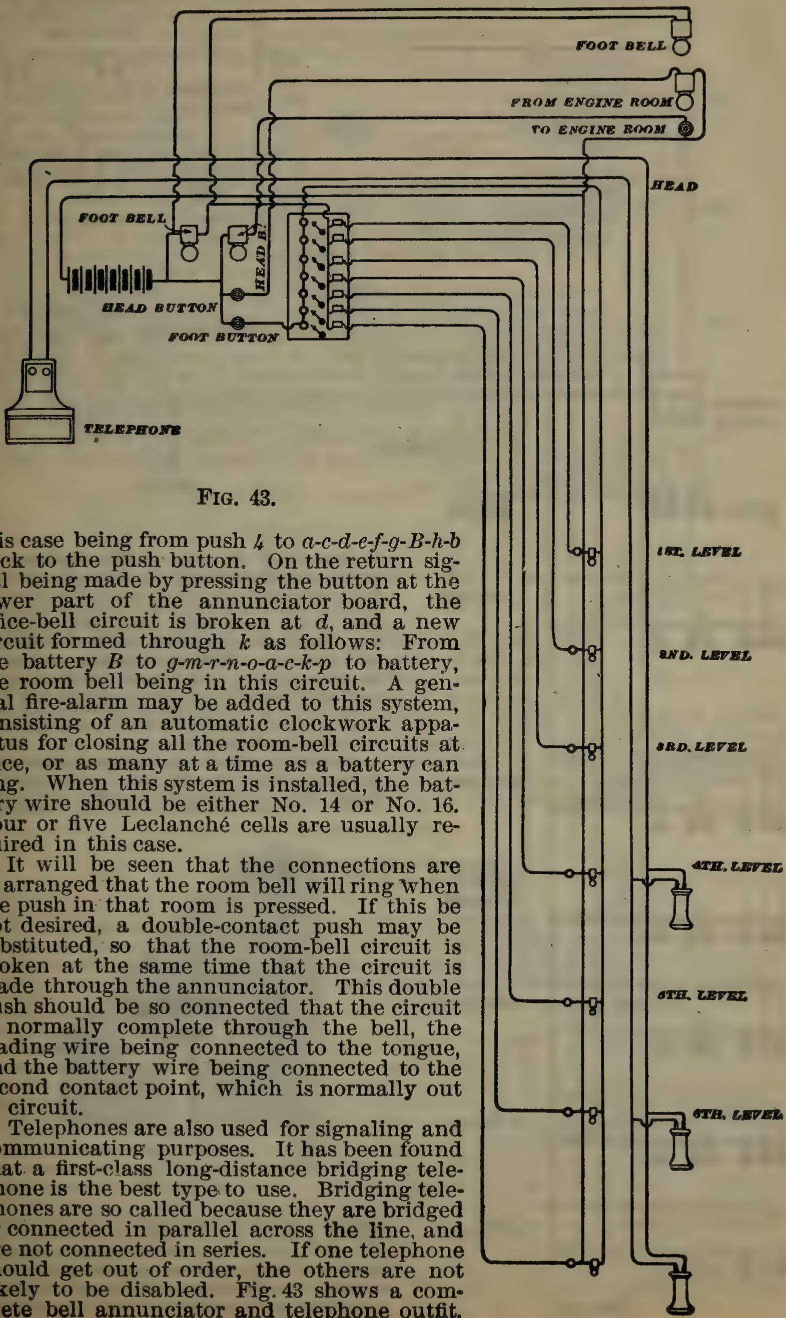


FIG. 43.

this case being from push *4* to *a-c-d-e-f-g-B-h-b* back to the push button. On the return signal being made by pressing the button at the lower part of the annunciator board, the office-bell circuit is broken at *d*, and a new circuit formed through *k* as follows: From the battery *B* to *g-m-r-n-o-a-c-k-p* to battery, the room bell being in this circuit. A general fire-alarm may be added to this system, consisting of an automatic clockwork apparatus for closing all the room-bell circuits at once, or as many at a time as a battery can ring. When this system is installed, the battery wire should be either No. 14 or No. 16. Four or five Leclanché cells are usually required in this case.

It will be seen that the connections are so arranged that the room bell will ring when the push in that room is pressed. If this be not desired, a double-contact push may be substituted, so that the room-bell circuit is broken at the same time that the circuit is made through the annunciator. This double push should be so connected that the circuit is normally complete through the bell, the leading wire being connected to the tongue, and the battery wire being connected to the second contact point, which is normally out of circuit.

Telephones are also used for signaling and communicating purposes. It has been found that a first-class long-distance bridging telephone is the best type to use. Bridging telephones are so called because they are bridged or connected in parallel across the line, and are not connected in series. If one telephone should get out of order, the others are not likely to be disabled. Fig. 43 shows a complete bell annunciator and telephone outfit,

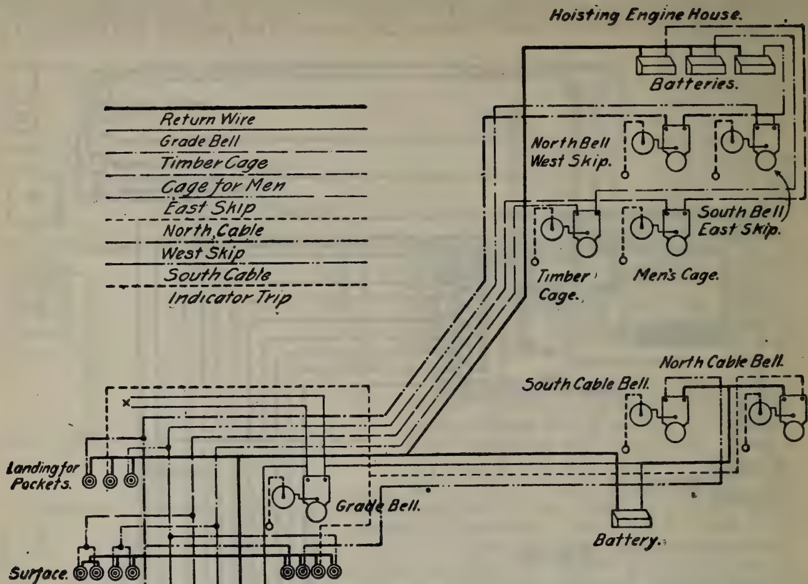
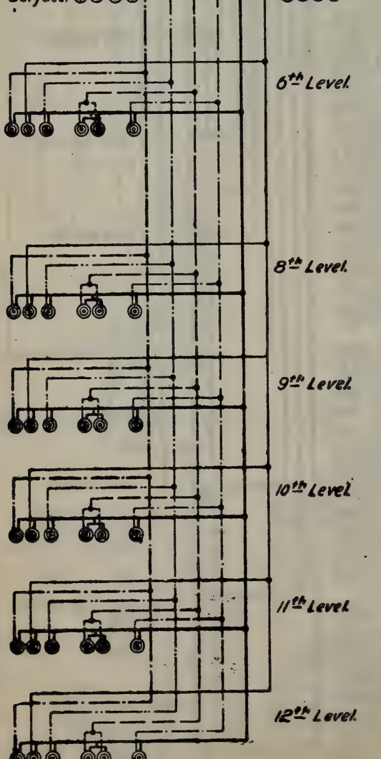



FIG. 44.

as installed in one of the anthracite coal mines of the D., L. & W. R. R. Co. It will be noticed that bridging instruments are used and that each bell in the shaft is provided with a return-call button. This bell wiring should be put up in a substantial manner, and it is best, if possible, to run all the wires down the shaft in the shape of a lead-covered cable.

Another shaft-signaling apparatus is shown in Fig. 44, as used at the West Vulcan mines, Mich. Fig. 45

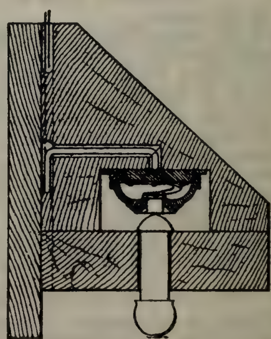


FIG. 45.

shows a form of waterproof push button used at the same mine. Fig. 46 shows the arrangement of flash signals as used in Montana. This consists of a switch cut into this main circuit at

each level of the mines. By pulling out the handle bar of the switch, the lights on this circuit can all be flashed at once, and by a properly arranged code of flash signals, the system can be used for communicating between the surface to any part of the mine, and between different portions of the mine.

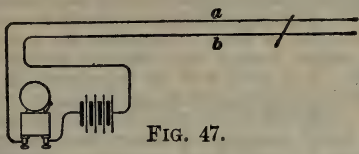


FIG. 47.

A system of signaling by which signals can be sent to the engine room from any point along the haulage road is shown in Fig. 47. The conductors a and b, leading from the battery run parallel to each other along the roadside, and about 6 in. apart. A short iron rod, placed across the wires a, b, signals to the engineer, or by simply bringing the two wires together a signal may be sent.

When the engineer hauls from different roads, the signaling system should be supplemented with indicators, so that when the bell rings the indicator would show from which point the signal came, and in case several signals were given at the same time, the engineer should not heed any until the indicator shows that a complete signal came from one place.

A system of signaling for showing whether or not a section of track is occupied by another motor is shown

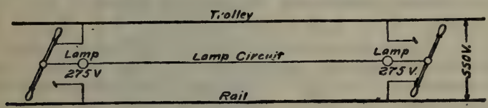


FIG. 48.

in Fig. 48. White lights indicate a clear track and darkness an occupied section. A single-center hinge, double-handle switch at each signal station is used and a touch of the handle throws the switch in the desired direction. The switches are placed in the roof, $4\frac{1}{2}$ ft. above rails within easy reach of motorman. Fig. 48 shows the connections. Each switch is provided with a spring (not shown in the figure) which, drawing across the center hinge, when the handles are in their central position, insures a perfect contact when the switch is inclined toward either the trolley or rail-terminal plug.

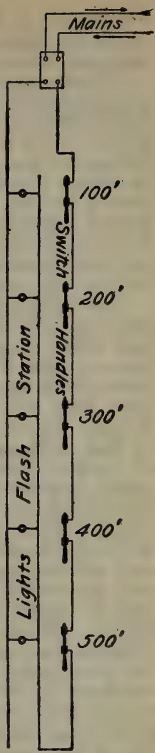


FIG. 46.

PROSPECTING.

The prospector should have a general knowledge of the mineral-bearing strata, and should know from the nature of the ledges exposed whether to expect to find mineral or not. He should also possess such a knowledge of the use of tools as will enable him to construct simple structures, and a sufficient experience in blacksmithing to enable him to sharpen picks and drills, or to set a horseshoe, if necessary.

Outfit Necessary.—The character of the prospecting being carried on will have considerable effect on the outfit necessary, which should always be as simple as possible. In general, when operating in a settled country, the outfit is as follows: A compass and clinometer for determining the dip and strike of the various measures encountered; a pick and shovel for excavating, and, where rock is liable to be encountered, a set of drills, hammer, spoon for cleaning the holes, tamping stick, powder and fuse, or dynamite fuse and cap; a blowpipe outfit; a small magnifying glass; an aneroid barometer for determining elevations, and a small hand pick; the latter should weigh about $1\frac{3}{4}$ lb., and should have a pick on one end and a square-faced hammer on the other, the handle being from 12 to 14 in. long.

If the region under consideration has been settled for some time, there will probably be geological, county, railroad, or other maps available.

These may not be accurate as to detail, but will be of great assistance in the work on account of the fact that they give the course of the railroads, streams, etc.

When operating in a mountainous region, away from a settled country, and especially when searching for precious metals, the following materials, in addition to that already mentioned, may be required: A donkey or pony packed with a couple of heavy blankets, an A tent, cooking utensils, etc.; a supply of flour, sugar, bacon, salt, baking powder, and coffee, sufficient for at least a month. It is also well to take some fruit, but all fruit containing stones or pits should be avoided, as they are only dead weight, and every pound counts. For the same reason, canned goods should be avoided, on account of the large amount of water they contain. A healthy man will require about 3 lb. of solid food per day. Many prefer to vary the diet by taking rice, corn meal, beans, etc., in place of a portion of the flour.

The additional tools necessary are an ax, a pan for washing gold ore, making concentrating tests, etc., and, in some cases, an assay furnace and outfit packed upon another animal. Where game is abundant, a shotgun or rifle will be found useful for supplying fresh meat. In regions abounding in swamps it becomes necessary to operate from canoes, or to take men for porters or packers, who carry the outfit on their backs or heads. These men will carry from 60 to 125 lb.

Plan of Operations.—When the presence of mineral is suspected in a tract of land, a thorough examination of the surface and a study of the exposed rocks, in place, may result in its immediate discovery, or in positive proof of its absence; or it may result in still further increasing the doubt of, or the belief that, it does exist. The first procedure in prospecting a tract of land is to thoroughly traverse it, and note carefully any stains or traces of smut, and all outcrops of every description; and, whenever possible, take the dip and the course of the outcrop with a pocket compass. Any fossils should also be carefully noted, to assist in determining the geological age of the region. These outcrops are frequently more readily found along roads or streams than any other place on the tract. In traveling along the streams, the prospector should pay particular attention to its bed and banks, to see whether there are any small particles of mineral in the bed of the stream, or any stains or smut exposed along the washed banks. If small pieces of mineral are found in the stream, a search up it and its tributaries will show where the outcrop from which the find came is located. When the ravines and valleys are so filled with wash that no exposures are visible, and nothing is gained by a careful examination of them, the prospector must rely on topographical features to guide him.

Any gold present in the vein material usually remains in the float as free or metallic gold, but other valuable metals are often leached out. The fact that the float itself may be barren does not indicate that it may not have come from a very rich deposit, and hence it will often pay to follow barren float, since the outcrop of the vein itself is often either entirely barren, low grade, or of a different nature from the deeper deposits. In cases where there are no outcrops or any other surface indications, it would become necessary to sink shafts or test pits, or to proceed by drilling.

The absence of any indication of mineral in the soil may not prove that there is not an outcrop near at hand, for the soil is frequently brought from a distance, and bears no relation to the material underlying it. In like manner, glacial soil often contains débris transported from deposits many miles away; but such occurrences can usually be distinguished by the general character of the associated wash material.

Frequently, the weathered outcrop of a deposit has been overturned or dragged back upon itself, so as to indicate the presence of a very thick deposit. For this reason, any openings made to determine the character of the material should be continued until the coal or other mineral is of a firm character, and both floor and roof are well exposed. Sometimes, in the case of steeply pitching coal beds, the surface may be overturned for a considerable depth, so that it is difficult to tell which is the roof and which is the floor. Usually, if Stigmariæ are found in the rocks of one wall, it is supposed that this wall is the floor of the seam, while if Sigillariæ, fern leaves, etc. are found in the wall rock, it is probably the roof of the deposit. These indications are not positive proof, for both of these fossils may occur in either the top or bottom wall of a coal deposit, though they are usually found in the positions noted. Coal, clay, gypsum, salt, etc. usually occur in unaltered deposits, i. e., in rocks that have not undergone metamorphism.

The accompanying table gives the names of the various geological periods, both as they occur in America and their foreign equivalents, together with the name of the principal form of life during each period. The various terms employed in geology are defined in the glossary.

Ages	Periods	Eras	American Periods	Foreign Equivalents	
Cenozoic	Pleistocene	Quaternary	Recent Champlain Glacial	Recent Pleistocene	Age of Man
	Neocene	Tertiary	Pliocene	Pliocene	Age of Mammals
			Miocene	Miocene	
	Eocene		Eocene	Eocene	
Mesozoic	Cretaceous	Cretaceous	(Laramie Series) Upper Cretaceous	Upper Cretaceous	Age of Reptiles
			Lower Cretaceous (Dakota Group) (Comanche Group)	Lower Cretaceous or Neocomian	
	Juratrias	Jurassic	Alantosaurus Beds	Oölite Lias	
		Triassic	Connecticut River Beds	Keuper & Rhætic Muschelkalk Bunter Sandstein	
Paleozoic	Carboniferous	Carboniferous	Permian	Permian	Age of Amphibians or Age of Acrogens (plants of the coal period)
			Carboniferous or Coal Measures.	Carboniferous or Coal Measures	
			Subcarboniferous	Mountain Limestone	
	Devonian	Devonian	Catskill. Chemung.	Old Red Sandstone	Age of Fishes
			Hamilton		
			Corniferous		
			Oriskany		
	Silurian.	Upper Silurian	Helderberg	Ludlow	
			Onondaga. Salina.		
			Niagara	Wenlock Llandovery	
		Lower Silurian	Trenton	Bala or Caradoc Llandeilo Flags	Age of Invertebrates
			Canadian	Arenig	
	Cambrian	Cambrian or Primordial	Potsdam	Tremadoc Slates Lingula Flags	
			Acadian	Menevian Solva	
			Georgian	Caerfai	
Eozoic		Algonkian	Huronian	Archean	No Distinct Organic Remains
		Archean	Laurentian		No Organic Remains

Metals and metallic ores usually occur in rocks that have undergone more or less metamorphism. This change may have been accompanied by heat and volcanic disturbances sufficient to render the rocks thoroughly crystalline, or it may simply have been the converting of limestone into dolomite.

The prospector for metals usually avoids regions in which the rocks have been wholly unaltered; while, on the other hand, a region covered by extensive flows of basalt is generally barren. As the vein filling of most metal-bearing deposits has been deposited from circulating water, it stands to reason that porous rock formations are more favorable to the occurrence of metallic ores than are hard, dense, rock formations. As a rule, ore deposits are more common at the junction of two dissimilar rock formations, as, for instance, the contact between limestone and porphyry.

When a prospector is operating in any particular region, it is best to study carefully the conditions of that region before proceeding, as such factors as lack of rain, frozen ground, etc. may have played an important part in determining the character of placer or fragmentary deposits, and the outcrop and surface appearance of other deposits. Experience obtained in one region is frequently very misleading when applied in another.

Coal or Bedded Materials.—The presence of the outcrop of any bed may often be located by a terrace caused by the difference in the hardness of the strata; but as any soft material overlaying a hard material will form a terrace, it is necessary to have some means of distinguishing a coal or ore terrace from one caused by worthless material. Usually, the outcrop of a coal terrace will be accompanied by springs carrying a greater or less amount of iron in solution, which is deposited as ochery films upon the stones and vegetable matter over which the water flows. The outcrops of beds of iron or other ores are very frequently marked by mineral springs. Sometimes the outcrop of a bed will be characterized by a marked difference in the vegetation, as, for instance, the outcrop of a bed of phosphate rock by a luxuriant line of vegetation, the outcrop of a mineral bed by a lack of vegetation, the outcrop of a coal bed contained between very hard rocks by more luxuriant vegetation than the surrounding country, etc. Some indication as to the dip and strike of the material composing the bed may be obtained by examining the terrace and noting the deflections from a straight line caused by the changes in contour of the ground. If the variation occasioned by a depression is toward the foot of the hill, the bed dips in the same direction with the slope of the ground; but if the deflection is toward the top of the hill, the dip is the reverse from the slope of the ground, or into the hill. After any terrace or indication of the outcrop of a bed has been discovered, it will be necessary to examine the outcrop by means of shafts, tunnels, or trenches. The position of such openings will depend on the general character of the terrace. If the dip appears to be with the hill, a trench should be started below the terrace and continued to and across it; while if the dip appears to be into the hill, it may be best to sink a shallow shaft above the terrace.

Formations Likely to Contain Coal.—No coal beds of importance have as yet been found below the Carboniferous period, but coal may be looked for in any stratified or sedimentary rocks that were formed after this period, although the bulk of the best coal has, up to the present time, been found in the Carboniferous period. As a rule, highly metamorphic regions contain no coal, and the same may be said of regions composed of volcanic or igneous rocks. An examination of the fossils contained in the rocks of any locality will usually determine whether they belong to a period below or above the Carboniferous, and hence whether there is a probability of the formations containing coal. On account of this fact, the prospector should familiarize himself with the geological periods, and, by referring to any elementary geology, with the most common fossils of the various periods. The rocks most common in coal measures are sandstones, limestones, shale, conglomerates, fireclays, and, in some localities, the coal deposits are frequently associated with beds of iron ore.

Ore deposits, as is well known, are generally found in mountainous districts, rather than in the undisturbed horizontal strata of the plains and mountain parks—usually deep in the core and center of the mountain system, rather than along their flanking foot-hills. Consequently, not only are the prairies and flat portions of the mountain parks to be avoided, but also the zone of uptilted strata on the edges of prairies and parks, commonly called *hogbacks*. These hogbacks are the natural "habitat" of such

economic products as coal, petroleum, building stone, clays, etc., but not often of the precious metals. The reason for this appears to be that the latter are commonly found to be associated with evidences of more or less heat. In the Rocky Mountains they are rarely found except where volcanic eruptions have at some time been active, or where the strata have been changed or metamorphosed and crystallized by heat.

As metallic ore bodies occupy fissures and other openings in the earth's crust, we must go to regions where the greatest disturbances and uplifts have occurred, accompanied by the greatest rending and contortions of the rocks, and eruptions of volcanic matter.

As a broad assertion, we may say that the greater part of any mountain region is a prospecting field, with the exception of those areas we have restricted as unpromising. But over this wide area of more or less metamorphosed and crystalline rocks, there are regions and localities where the precious metals have already been found, and others where on geological grounds they are most likely yet to be found, and those are generally where eruptive forces have been especially active, where once molten eruptive rocks are most abundant, and the disturbance and crystallizing of the strata most pronounced.

Position of Veins and Ore Deposits.—Ores, as a rule, are to be looked for at the junction of any two dissimilar rocks, rather than in the mass of those rocks. However, there are many exceptions to this, where the mass of a decomposed dike or sheet of porphyry has been impregnated by free gold or gold-bearing pyrites, and the whole rock is practically a gold vein. In this mass, the richest gold is often found in a network of little quartz veins running through the porphyry mass. Some of our richest gold mines are found in "rotten," decomposed, oxidized dikes and sheets of porphyry; but this is rarely the case with lead-silver ores, which frequent rather the lines of contact in limestones or in fissure veins in granite. The Cambrian quartzites a few years ago were rather avoided by the prospectors, their extreme hardness presenting great difficulties in mining, and from the fact that they were generally supposed to be barren. The late discoveries of very rich gold deposits in them, and of similar deposits in quartzites of a later age, have drawn more attention to them. The gold has been found in a free state associated with oxide of iron in cavernous deposits, and in close proximity to eruptive rocks. In the granitic rocks, both gold and silver occur in fissure veins associated with pyrites, galena, etc. These fissures, occupied by mineralized quartz veins, may occur in the granite or gneiss alone, or be at the contact of these rocks with a porphyry dike.

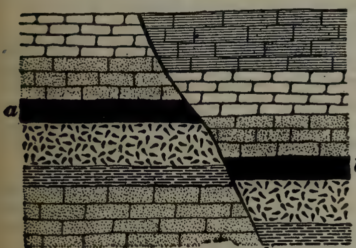


FIG. 1.

Veins in overflows of volcanic lava generally fill a fissure having a more or less steep inclination, penetrating the lava sheets, caused probably by shrinkage of the molten lava on cooling. These fissures, in some cases, are likely to be limited in depth to the thickness of the lava sheet. Where, in a few rare cases, the fissure has been traced down to the underlying granite or some other rock, it has come abruptly to an end.

Underground Prospecting.—Frequently a seam or deposit becomes faulted or pinched out underground, and it is necessary to continue the search by means of underground prospecting. Underground prospecting is, to a large extent, similar to surface prospecting, the underground exposures being simply additional faces for the guidance of the engineer. In the case of coal beds or similar seams, if a fault or dislocation is encountered, the manner of carrying on the search will depend on the character of the fault. Where sand faults or washouts are encountered, the drift or entry should be driven forwards at the angle of the seam until the continuation of the formation is encountered, when a little examination of the rocks will indicate whether they are the underlying or overlying measures. In the case of dislocations or throws, the continuation of the vein may be looked for by **Schmidt's law of faults,** which is as follows: *Always follow the direction of the greatest angle.* It has been discovered by observation that, in the majority of cases, the hanging-wall portion of the fault has moved down, and on this

account such faults are commonly called *normal faults*. For instance, if the bed *a b*, Fig. 1, were being worked from *a* toward the fault, upon encountering the fault, work would be continued down on the farther side of the fault toward *d*, until the continuation of the bed toward *b* was encountered. In like manner, had the work been proceeding from *b*, the exploration would have been carried up in the direction of the greatest angle, and the continuation toward *a* thus discovered. A reverse fault is one in which the movement has been in the opposite direction to a normal fault. Especially in the case of precious metal mines, where the material occurs as perpendicular or steeply pitching veins, faults are liable to displace the deposit, both horizontally and vertically, in which case it may be difficult to determine the direction of the continuation of the ore body; but frequently pieces of ore are dragged into the fault, and these serve as a guide to the miner, and indicate the proper direction for exploration. Where a bed or seam is faulted, its continuation can frequently be found by breaking through into the measures beyond, when an examination of the formation will indicate whether the rocks are those that usually occur above or below the desired seam.

Prospecting for Placer Deposits.—Placers are fragmental deposits from water in which the heavier minerals have been concentrated in certain portions, usually next the underlying, or bed, rock. The materials that are recovered from placer deposits are metallic gold, tinstone, monazite, sand, or precious stones. Placer deposits are modern or ancient. Modern placers are deposits of washed material, or débris, in the beds or along the banks of streams that are either now in existence or existed in comparatively recent times. Placer deposits may also occur in deposits along the seashore. Ancient placers are fragmental accumulations, similar to the modern placers, which have been buried under accumulations of strata or flows of lava, and they may or may not have become consolidated into rock.

At times, placers are very compact, owing to the presence of large quantities of oxide of iron or calcium carbonate, or similar cementing material. Often, in the case of modern placers, the streams, or other sources of water that deposited the material, have changed their course so that the placer deposit is now high up in the benches bordering the streams, or, possibly, even on the top of the present hills. Such deposits are commonly called *bench deposits*, while those along the sides of the streams below the high-water mark are called *bar deposits*, *diggings*, or *placers*.

Frequently, a large portion of the gold or other valuable material is found in pockets or irregularities in the bed rock, but the pot holes under waterfalls are frequently barren of gold, on account of the fact that the current there was sufficiently swift to wash everything out, either heavy or light. When the soil is saturated with water, the mass may partake of the nature of a semifluid through which the heavy particles of gold settle until they accumulate on the bed rock.

When prospecting for placers, the miner examines the country for any indications of present or ancient watercourses in which the deposits of placer material have been formed. He pans the dirt from any deposits discovered, to see if it contains *colors* (small particles of metallic gold). If colors are found, more extensive operations are in order, and hence he sinks to bed rock and examines the material thoroughly, to see if it contains a paying quantity of the valuable mineral.

The form of placer deposit in dry or arid regions differs from that in regions where the rivers have a continuous flow, on account of the fact that the deposits are largely the result of sudden rushes of water partaking of the nature of cloudbursts, hence the rich portions in the placer material are very irregular, and are rarely situated on bed rock, but are usually found on any strata that formed the bottom of the ravine during the sudden rush of water. During the rainy season in arid regions, the surface soil is sometimes softened for a few inches, so that it becomes practically a mud, and particles of gold that it may contain tend to settle to the bottom of the soft portion, thus rendering the surface barren. This barren surface may be subsequently washed away by the rain, or blown away as dust during the dry season. The repeating of this process year after year results in the removal of considerable of the original surface and the formation of a rich stratum just below the grass roots. Prospectors in arid regions, who have been used to operating in an ordinarily well-watered country, are frequently deceived by finding this rich ground so high up in the deposit, not knowing that it is no indication as to the value of the material at a greater depth.

In many cases, in the arid regions the portion of the deposit upon bed rock is entirely barren. In like manner, frozen ground may play an important part in the formation and distribution of the values in placer deposits.

Gems and precious stones are prospected for in a manner similar to that employed in searching for placer material, and are usually found in alluvial deposits, from which they are obtained by washing. In a few cases gems are found in the rocks themselves; as, for instance, diamonds in the hard matrix that occurs as pipes or chimneys in metamorphic rocks, and which, upon exposure to the atmosphere, becomes decomposed, so that the stones are easily removed. Some of the corundum minerals are found in limestone and metamorphic or crystalline rocks. Turquoise usually occurs in veins, the outcrop of which is stained with carbonate of copper. In most cases, it does not pay to extract gems from rock formations when the rock is extremely hard, owing to the fact that the gems are liable to become broken in separating them from the rock matrix.

For gem prospecting, the following *outfit* has been recommended: A shovel and pick; two sieves, one of 2 or 3 meshes to the linear inch, and the other of 20 or more meshes to the inch (the coarse sieve should be arranged to fasten on top of the finer one for use together); a tub in which the sieves can be submerged in water; an oilcloth on which to sort the gravel; several stones and crude gems as a scale of hardness; a small pocket magnifying glass, and a dichroscope. In some cases, a portion of the outfit is dispensed with. The use of the outfit may be explained as follows: The tub is partially filled with water, the two sieves fastened together, and a shovelful of material placed in the upper one, when they are submerged in water, the large stones cleaned and examined, and all of the fine material worked through the upper sieve, which is then removed, the material on it examined and disposed of. The material in the fine sieve is then washed until free from clay, when a little jigging motion in the water will carry the lighter material to the top. The sieve is then quickly inverted and the material dumped out on the oilcloth, thus bringing the heavier stones to the top. The various pieces should now be examined with the magnifying glass, scale of hardness, etc., and the identity of any doubtful colored gems settled, by means of the dichroscope. Few precious stones are of sufficient specific gravity to be concentrated in distinct beds, like gold or tinstone, but they are usually fairly well concentrated and freed from much of the lighter worthless material.

Value of Free Gold per Ton of Ore.—The accompanying table was prepared by Mellville Atwood, F. G. S., and its use may be explained as follows: If a 4-lb. sample of quartz be crushed, the gold separated by panning and

VALUE OF FREE GOLD PER TON OF ORE.
(*Risdon Iron Works.*)

Weight, Washed Gold. 4-Lb. Sample. Grains.	Fineness, 780. Value per Oz., \$16.12.	Fineness, 830. Value per Oz., \$17.15.	Fineness, 875. Value per Oz., \$18.08.	Fineness, 920. Value per Oz., \$19.01.
5.0	\$83.97	\$89.36	\$94.20	\$99.05
4.0	67.18	71.49	75.36	79.24
3.0	50.38	53.61	56.52	59.43
2.0	33.59	35.74	37.68	39.62
1.0	16.79	17.87	18.84	19.81
.9	15.11	16.08	16.95	17.82
.8	13.43	14.29	15.07	15.84
.7	11.75	12.51	13.19	13.86
.6	10.07	10.73	11.30	11.88
.5	8.40	8.93	9.42	9.90
.4	6.71	7.14	7.53	7.92
.3	5.03	5.36	5.65	5.94
.2	3.36	3.57	3.76	3.96
.1	1.68	1.78	1.88	1.98

amalgamation, the quicksilver volatilized by blowpiping or otherwise, and the resulting button weighed, the value of the ore per ton of 2,000 lb. will

be found opposite the weight of the button. The values are given for fineness of gold varying from 780 to 920.

To determine the value of gravel, a 6-lb. sample will give the same results as that obtained from a 4-lb. sample of quartz, on account of the fact that 18 cu. ft. of gravel measured in a bank weigh 1 ton, or 2,000 lb.; hence, a cubic yard of gravel measured in a bank weighs 3,000 lb., and for this reason a sample one and one-half times as large as that required for quartz must be taken. In case the gravel is of low grade, a sample ten times as large, or 60 lb., may be taken, in which case the value opposite the weight of the button will have to be divided by 10.

As an example, in the use of the table we may suppose that a button from 4 lb. of ore or 6 lb. of gravel weighs 3.8 gr., and that the fineness of the gold is 830. Opposite 3 in the table we will find $53.61 as the value of the button in dollars containing 3 gr. of gold, and opposite .8 we will find $14.29. The sum of these is $67.90, the value of the ore per ton, or the gravel per cubic yard.

EXPLORATION BY DRILLING OR BORE HOLES.

Earth Augers.—When testing soil or searching for placer gold, sand, soft iron, or manganése ores, and similar materials that usually occur comparatively near the surface, hand augers may be employed to great advantage. A good form of hand auger consists of a piece of flat steel or iron, with a steel tip, twisted into a spiral about 1 ft. long, and having four turns. The point is split and the tips sharpened and turned in opposite directions and dressed to a standard width, usually 2 in. The auger is attached to a short piece of 1″ pipe, and is operated by joints of 1″ pipe, which are coupled together with common pipe couplings. The auger is turned by means of a double-ended handle having an eye in the center through which the rod passes.

The handle is secured by means of a setscrew. In addition to the auger, it is well to have a straight-edged chopping bit for use in comparatively hard seams. This may be made from a piece of 1⅜″ octagon steel, with a 2″ cutting edge. The upper end of the steel is welded on to a piece of pipe similar to that carrying the auger. When the chopping bit is employed, it is necessary to have a heavy sinking bar, which may be made from a piece of solid 1¼″ iron bar, fitted with ordinary 1″ pipe threads on the ends. Prospecting can be carried on to a depth of from 50 to 60 ft. with this outfit. The number of men necessary to operate the rods varies from 2 to 4, depending on the depth of the hole being drilled. When more than 30 ft. of rods are in use, it is usually necessary to have a scaffold on which some of the men can stand to assist in withdrawing the rods. When withdrawing the rods, to remove the dirt, they are not uncoupled unless over 40 ft. of rods are in use at one time, and sometimes as many as 50 or 60 ft. are drawn without uncoupling.

Percussion or **churn drills** are frequently employed in drilling for oil, water, or gas, and were formerly much used in searching for coal and ores, but, owing to the fact that they all reduce the material passed through to small pieces or mud, and so do not produce a fair sample, and to the fact that they can only drill perpendicular holes, they are at present little used in prospecting for either ore or coal.

The cost and rate of drilling by means of a percussive or churn drill varies greatly, being affected much more by the character of the strata penetrated than is the case with the diamond drill. In the case of highly inclined beds of varying hardness, the holes frequently run out of line and become so crooked that the tools wedge, and drilling has to be suspended. For drilling through moderately hard formations, usually encountered in searching for gas or water, such as sandstones, limestones, slates, etc., the accompanying costs, from the American Well Works, Aurora, Ill., may be taken per foot for wells from 500 to 3,000 ft. deep for the central or eastern portion of the United States at present (1900). This cost includes the placing of the casing, but not the casing itself.

COST OF WELL-DRILLING.

Size of Well. Inches.	Cost per Foot.
6	$1.50
8	2.25
10	3.00
12	5.00
15	8.00

When drilling wells for oil or gas to a depth of approximately 1,000 ft., using the ordinary American rig with a cable, the cost is sometimes reduced to as little as 65 cents per foot for 6″ or 8″ wells. This is when operating in rather soft and known formations. From 15 to 40 ft. per day of 24 hours is usually considered a good rate of drilling, though in soft materials as much as 100 ft. may be drilled in a single day, and at other times, when very hard rock is encountered, it is impossible to make more than from 1 to 2 ft. per day.

The **diamond drill** is the only form that has been universally successful in drilling in any direction through hard, soft, or variable material. Even in the use of the diamond drill, many difficulties present themselves, and demand careful study in adapting the form of apparatus to the work in hand, and in rightly interpreting the results obtained from any set of observations.

NOTE.—See "Mines and Minerals" for articles on Diamond-Drilling Practice, by H. M. Lane, August, 1899, to January, 1900, Vol. XX.

Selecting the Machine.—It is not economy to employ a machine of large capacity in shallow explorations, as the large machines are provided with powerful motors, and hence do not work economically under light loads. When a large machine is operating small rods on light work, the driller cannot tell the condition of the bit, or properly regulate the feed. The machine should possess a motor of sufficient capacity to carry the work to the required depth, but where much drilling is to be done, it is usually best to have two or more machines, and to employ the small ones for shallow holes, and the large ones for deep holes.

All feed mechanisms employed in diamond drilling may be divided into two classes: (1) Those that are an inverse function of the hardness of the material. This class includes friction, spring, and hydraulic feeds. (2) Those in which the feed is independent of the material being cut, as in the case of the positive gear-feed.

The first class is advantageous when drilling through variable measures in search of fairly firm material, which does not occur in very thin beds or seams. On account of the fact that this class of feed insures the maximum amount of advance of which the bit is capable in the material being cut, the danger is that the core from any thin soft seam may be ground up and washed away, without any indication of its presence having been given.

The second class, or positive gear-feed, if properly operated, requires somewhat greater skill, but if used in connection with a thrust register, it gives reliable information as to the material being cut, and is especially useful when prospecting for soft deposits of very valuable material.

Size of Tools.—The size of tools and rods, and consequently the size of the core extracted, depends on the depth of the hole and the character of the material being prospected. When operating in firm measures, such as anthracite coal, hard rock, etc., it is best to employ a rather small bit, even when drilling up to 700 ft., or more, in depth. For such work, a core of from $\frac{15}{16}$ in. to $1\frac{3}{16}$ in. is usually extracted. The rate of drilling with a small outfit is very much greater than with a large one, owing to the fact that there is a small cutting surface exposed, and the rate of rotation of the rods can be much greater. When prospecting for soft materials, such as bituminous coal, valuable soft ores, or for disseminated ores, such as lead, copper, gold, silver, etc., it is best to employ a larger outfit and extract a core 2 or 3 in. in diameter, and sometimes even larger, even though a comparatively small machine is used to operate the rods.

Drift of diamond-drill holes, or the divergence from the straight line, often becomes a serious matter. This trouble may be minimized by keeping the tools about the bit as nearly up to gauge as possible. Core barrels, with spiral water grooves about them, answer this purpose very well if they are renewed before excessive wear has taken place.

Surveying of diamond drill-holes may be carried on by either one of two methods, depending on the magnetic conditions of the district. Where there is no magnetic disturbance, the system developed by Mr. E. F. MacGeorge, of Australia, may be employed. This consists in introducing into the hole, at various points, small tubes containing melted gelatine, in which are suspended magnetic needles and small plummets. After the gelatine has hardened the tubes are removed, and the angles between the center line of the tube, the plummet, and the needle noted, thus furnishing the data from which the course of the hole can be plotted. This method gives both the vertical and the horizontal drift.

Where there is magnetic disturbances the needle cannot be used, but a system brought out by Mr. G. Nolten, of Germany, has been quite extensively employed. In this case, tubes partly filled with hydrofluoric acid are introduced into the hole, at various points, and the acid allowed to etch a ring on the inside of the tube. After the acid has spent itself the tubes are withdrawn, and by bringing the liquid into such a position that it corresponds with the ring etched on the inside of the tube, the angle of the hole at the point examined can be determined. This method gives a record of the vertical drift of the hole only.

The **value of the record** furnished by the diamond drill depends largely on the character of the material sought. The core extracted is always of very small volume when compared with the large mass of the formation prospected, and hence will give a fair average sample only in the case of very uniform deposits. The value of the diamond drill for prospecting may be stated as follows: *More dependence can be placed on the record furnished by the diamond drill when prospecting for materials that occur in large bodies of uniform composition than when prospecting for materials that occur in small bunches or irregular seams.* To the first class belong coal, iron ore, low-grade finely disseminated gold and silver ores, many deposits of copper, lead, zinc, etc., as well as salt, gypsum, building stone, etc. To the latter class belong small but rich bunches of gold, silver mineral, or rich streaks of gold telluride.

The **arrangement of holes** has considerable effect upon the results furnished. If the material sought lies in beds or seams (as coal), the dip of which is fairly well known, it is best to drill a series of holes at right angles to the formation. If the material sought occurs in irregular bunches, pockets, or lenses, it will be necessary to drill holes at two or more angles, so as to divide the ground into a series of rectangles, thus rendering it practically impossible for any vein or seam of commercial importance to exist without being discovered. Where the surface of the ground is covered with drift and wash material, it may be best to sink a shaft or drill pit to bed rock, and locate the machine on bed rock. After this, several series of fan holes may be drilled at various angles from the bottom of the pit. Owing to the upward drift of diamond-drill holes, the results furnished from a set of fan holes drilled from a single position would make a flat bed appear as an inverted bowl, or the top of a hill. On this account, it is best to drill sets of fan holes from two or more locations, so that they will correct one another. If fan holes from different positions intersect the same bed, a careful examination of them will usually furnish a check on the vertical drift of the holes.

The **cost and speed of drilling** depend greatly on the formation being penetrated. As a rule, it is more expensive to sink the stand pipe than to do the subsequent drilling. Stand pipes may cost $5 or more per foot to sink, while the cost of drilling in firm rock varies from $0.50 to $2 per foot; in the case of difficult drilling, the cost may run over $4 per foot. Where a large amount of drilling has to be done, a fair average estimate for shallow holes up to 700 ft. deep would be $2 per foot, under such conditions as exist in most mineral districts of the United States. The cost of labor, fuel, etc., enter into the problem, and frequently affect it to a considerable extent.

The rate of drilling varies considerably, but in firm rock an average of 1 ft. per hour, including all delays for changing rods, etc., would be a fair average up to 700 ft. Greater speed than this could be made in soft shales or sandstones, and somewhat less in hard rock. The hardness of the rock affects the rate of drilling much less than does its character. A conglomerate rock containing loose pebbles that come out during the drilling, or a crystalline rock containing angular pieces that come out during drilling, will cause far greater trouble than the hardest material ever encountered in diamond drilling. The following tables will give some idea as to the cost of diamond drilling under various conditions.

The cost of drilling 2,084 ft. of hole in prospecting the ground through which the Croton aqueduct tunnel was to pass is given as follows:

814 ft. of soft rock (decomposed gneiss), in which an average of 23.1 ft. per day was drilled, at a cost of $1.15 per ft.

347 ft. of hard rock (gneiss), in which an average of 11.1 ft. per day was drilled, at a cost of $3.97 per ft.

923 ft. of clay, gravel, and boulders, in which from 6½ to 9 ft. per day were drilled, at a cost of $4.07 per ft.

The average progress per day in drilling the entire 2,084 ft. was 10.2 ft. per day.

In the Minnesota Iron Co.'s mines, at Soudan, Minn., the diamond drill is used for drilling holes from 10 to 40 ft. in depth in the back of the stopes, practically all the work being done in iron ore. The average cost per foot of drilling 13,512 ft. of hole was $0.7703, which was divided as follows:

Carbons	$0.34
Supplies, oil, etc.	0.07
Fuel	0.04
Repairs	0.05
Labor	0.2703
Total	$0.7703

The following tables give the cost of boring at two Ishpeming, Mich., mines:

TABLE I.

		Total Cost.	Cost per Ft.
Labor	400¼ days setter at $3.00 ... $1,200.75 372 days runner at 2.25 ... 837.00 230½ days runner at 2.00 ... 460.50 4½ days laborer at 1.75 ... 7.85	$2,506.10	$0.669
Carbon 68⅝ carats at $15.144		1,035.47	0.276
Bits, lifters, shells, barrels, and repairs		433.81	0.115
Oil, candles, waste, and supplies		128.09	0.035
Estimated cost compressed air		374.60	0.100
Total		$4,478.07	$1.195
Number holes drilled			28
Drilled in hematite			193 ft.
Drilled in jasper			646 ft.
Drilled in mixed ore			986 ft.
Drilled in dioritic schist			1,921 ft.
Total drilling			3,746 ft.
Number of 10-hour shifts drill was running, including moving and setting up			603
Amount drilling per 10-hour shift			6.2 ft.

TABLE II.

Underground drilling	6,075 ft.
Surface drilling	1,414 ft.
Stand pipe sunk	470 ft.
Total distance run	7,959 ft.
Actual drilling time underground	672 shifts
Actual drilling time on surface	165 shifts
Time of foreman, setter, moving, and stand-piping	1,314 shifts
Total time worked	2,151 shifts
Average progress per man per shift	3.70 ft.
Average progress per drill per shift actually running	8.95 ft.
Weight of carbon consumed	111.00 carats
Distance drilled per carat of carbon consumed	67.38 ft.

	Amount.	Per Ft.
Cost of carbon	$1,887.00	$0.237
Cost of supplies and oils	134.13	0.017
Cost of fuel	360.73	0.045
Cost of shop material, etc.	663.36	0.083
Pay roll	4,000.03	0.502
Total cost	$7,045.25	$0.884

RECORDS OF COST PER FOOT IN DIAMOND DRILLING.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Labor	.707	1.040	2.483	1.150	.581	1.615	1.030	1.720	1.189	1.284	.721	1.200	.939	.812	.984
Fuel	.094	.270	.256	.019	.000	.216	.090	.214	.157	.339	.419	.329	.126	.182	.251
Camp account	.373	.559	.789	.538	.295	.621	.384	.549	.516	.495	.519	.595	.644	.722	.636
Repairs	.139	.110	.294	.171	.135	.144	.103	.185	.154	.165	.040	.087	.138	.126	.116
Supplies ...	.034	.065	.039	.074	.023	.032	.011	.039	.048	.097	.020	.092	.076	.097	.088
Carbon	.263	.658	.859	.860	.843	1.587	.934	.684	.684	.733	.227	.209	.553	.239	.330
Supt.	.239	.322	.628	.040	.063	.192	.140	.305	.259	.172	.347	.220	.106	.196	.199
Total ...	1.849	3.024	5.348	2.852	1.940	4.407	2.692	3.696	3.007	3.285	2.293	2.732	2.582	2.374	2.604

A 5 holes, 1,066 ft.
Sandstone and marble.
B 1 hole, 1,293 ft.
Black slate and jasper.
C 3 holes, 478 ft.
Jasper, very hard.
D 5 holes, 780 ft.
Jasper, hard.
E 1 hole, 216 ft.
Iron slates.
F 1 hole, 174 ft.
Jasper and slate.
G 2 holes, 267 ft.
Jasper and slate.
H 3 holes, 410 ft.
Jasper.
I Average cost of total work of drilling 21 holes. Total of 4,684 ft.
J 2 holes, 634 ft.
Iron slates.
K 2 holes, 360 ft.
Schist and jasper.
L 6 holes, 1,350 ft.
Iron slates.
M 2 holes, 611 ft.
Schist, jasper, and quartzite.
N 6 holes, 2,091 ft.
Quartzite.
O Average cost of drilling 18 holes, 5,046 ft.

The following figures, taken from a letter written by T. F. Richardson, Departmental Engineer of Dam and Aqueduct Department, Metropolitan Water Board of Boston, and published by the U. S. Geological Survey, are of interest, as they show the rate and cost of diamond drilling under certain conditions. The costs do not take into account depreciation of machinery nor losses of time in moving machines, etc. The machines employed in this work were a Badger drill, manufactured by the M. C. Bullock Manufacturing Co., of Chicago, Ill., and an S-510 drill, manufactured by the Sullivan Machinery Co., Claremont, N. H.

The total amount drilled was 2,814 ft., the deepest hole being 286 ft. deep, and the average depths of holes about 60 ft. The amount accomplished per day was from 0 to 32 ft., the average amount being probably about 10 or 12 ft. per day. The cost of drilling varied very largely, both with the hardness of the rock and the condition of the rock as to being seamy.

The following was the cost of drilling 324.2 ft. of rather hard, tough diorite rock:

Labor	$341.25
Diamonds	74.30
Coal	17.50
Total	$433.05
Cost per foot	1.34

(86.6 ft. of this was drilled with a $1\frac{3}{8}''$ bit, and 237.6 ft. was drilled with a $1\frac{3}{4}''$ bit.)

Drilling 150.7 ft. of very hard syenite rock:

Labor	$158.00
Diamonds	298.69
Coal	10.50
Total	$467.19
Cost per foot	3.10

(Size of drill, $1\frac{3}{4}$ in.)

The following was the cost of drilling 286.1 ft. of soft schist rock:

Labor	$190.00
Diamonds	87.75
Coal	11.50
Total	$289.25
Cost per foot	1.01

(Size of drill, 1¾ in.)

The following figures will be of considerable interest, owing to the fact that the work is practically all of the nature of sinking stand pipes, the object of the exploration being to ascertain the depth of wash material and the character of the bed rock over the area of certain proposed dam sites in the southwestern portion of the United States, the work being carried on by the government. The machines used were made by the American Diamond Rock Drill Co., of New York, and had previously been employed in similar exploration along the line of the Nicaragua Canal.

Cost of operation per month of bed-rock exploration:

Foreman	$150.00	
6 laborers, at $1.50 per day, 28 days	234.00	
1 cook	45.00	
		$429.00
240 rations, at 60 cents		144.00
Total repairs, pipe and lumber for one party for 10 months	500.00	
Total commissary charges for team, feed, etc.	350.00	
Total moving	670.00	
Total sundry incidentals	200.00	
Total supervision	350.00	
Total, 10 months	$2,070.00	
Sundry expenses per month		230.00
Total cost per month		803.00
10 months, at $803		8,030.00
Total number of feet sunk		3,254.20
Total cost		$8,030.00
Cost per foot		2.46
Cost per hole, 7,227 ÷ 52		154.42

The drills were purchased second-hand from the Nicaragua Canal Co., and the other apparatus was new. If the original cost of all this machinery were distributed over the work, the results would be as follows:

Operation	$8,030.00
Machinery	1,600.00
Total cost	$9,630.00
Or average cost per foot	2.86

Both machines are still in good repair, after having been used in Nicaragua and in various localities in Arizona and California.

The total depths penetrated in all materials at the various dam sites are as follows:

	Covering.	Rock.	Total.
The Buttes	1,621.2	196.0	1,817.2
Queen Creek	357.8	55.6	413.4
Riverside	729.8	40.2	770.0
Dikes	80.0	0.0	80.0
San Carlos	143.2	30.4	173.6
Total	2,932.0	322.2	3,254.2

Magnetic Prospecting.—Bodies of magnetic iron ore are frequently discovered or located on account of their magnetic properties. Two forms of compasses are employed in this work: the dipping needle, or miners' compass, and the ordinary compass. The ordinary compass is used to find the center of magnetic attraction in the horizontal plane, and after this has been found the ground may be run over with the dipping needle, to locate the center of attraction by this means. The ordinary compass does not give good results when operating over a magnetic deposit, but is only useful in determining its outside edge, and thus locating its general position. The dipping needle differs from the ordinary compass in that the needle is hung in a vertical plane in place of horizontally, so that the needle is free to assume any position varying from the horizontal, depending on the downward component of magnetic attraction at that point. The vertical magnetic component at the point should be compensated for by balancing the dipping needle so that it will ordinarily stand horizontally when not affected by local disturbances.

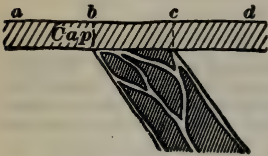


FIG. 2.

The actual work of prospecting may be carried on as follows: If there were an outcrop of a vein of magnetic material, as shown in Fig. 2, covered with a capping of wash material, the preliminary prospecting would be carried on as shown in Fig. 3, the dipping needle being carried backwards and forwards zigzag across the deposit, noting the point of maximum dip in each case and establishing a stake there as indicated by the crosses. After these stakes had all been established, an average straight line would be struck through them that would follow the course of the deposit as nearly as possible. Stakes would be placed at the ends of this line, as at *X* and *Y*, and the line *X Y* divided off into 100′ distances by means of stakes marked *A*, *B*, etc. Lines at right angles to the original line would then be turned off at these 100′ points, and stakes placed every 10 ft. upon the branch lines. These points on the branch lines would be lettered with small letters, corresponding to the large letter on the line *X Y*, as shown in Fig. 4, which represents the observations taken at the first station. The dip would be noted at each one of the 10′ stations, and recorded in the note book. A convenient method of keeping the notes is to have a vertical line down the center of the page for the line *X Y*, and other vertical lines to the right and left of it for the individual stations 10 ft. apart, each side of the main line, the horizontal lines across the page being lettered *A*, *B*, etc., the stations to the right and left being marked with primes and subscripts of the small letters corresponding to the line. After the observations have been taken, lines may be drawn through points of equal dip and equal deflection (isogonic lines). By this means the general form of the bed is determined.

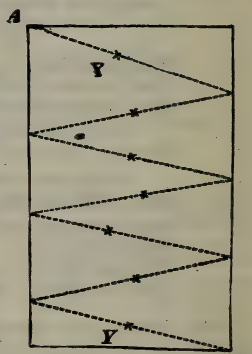


FIG. 3.

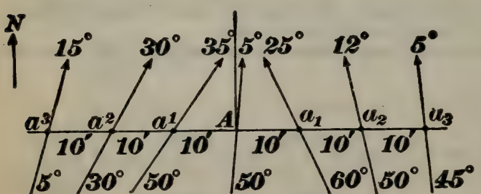


FIG. 4.

The maximum dip, in the case of an inclined deposit like that shown in Fig. 2, would occur at *c*, over the hanging wall of the outcrop, the dip at *b* being considerably less, and the dip at *a* being less than that at *b*. After the center of magnetic attraction has been discovered, prospecting may be continued by means of the diamond drill, or by sinking shafts or test pits. Sometimes, where deposits of magnetic iron ore have been eroded, the sands near the surface may contain such a considerable amount of magnetic disturbance as to indicate the presence of a body of iron ore, while in reality there may be such a small quantity disseminated through the sand that it could not be made to pay for its removal.

Any body of magnetic iron ore is affected by polarity, and one end of it will attract one end of the dipping needle, while the other end will attract the opposite end. Where the body is badly broken up, this dip of the needle may be reversed several times in a comparatively short distance.

Prospecting for Petroleum, Natural Gas, and Bitumen.—Among the surface indications of petroleum and bitumen may be mentioned white leached shales or sandstones, shales burned to redness, fumaroles, mineral springs, and deposits from mineral springs. Also natural gas, springs of petroleum oil and naphtha, porous rocks saturated with bitumen, cracks in shale, and other rock partly filled with bitumen. Petroleum is never found in any quantity in metamorphic rocks, but always in sedimentary deposits. Bitumen can be told from coal, vegetable matter, iron, manganese, and other minerals, which it sometimes closely resembles, by its odor and taste, also by the fact that it melts in the flame of a match or candle, giving a bituminous odor. (Iron and manganese do not fuse, and coal and vegetable matter burn without fusion.) Bitumen is also soluble in bisulphide of carbon, chloroform, and turpentine, usually giving a dark, black, or brown solution. Frequently, springs or ponds have an iridescent coating of oil upon the surface. Sometimes iron compounds give practically the same appearance, but the iron coating can always be distinguished from the oil by agitating the surface of the water, when the iron coating will break up like a crust of solid material, while the oil will behave as a fluid, and tend to remain over the entire surface even when it is agitated.

Frequently, bubbles of gas are seen ascending from the bottoms of pools or creeks. These may be composed of carbureted hydrogen or natural gas, which is a good indication of the presence of petroleum or bitumen; they may be composed of sulphureted hydrogen or carbonic-acid gas. Carbureted hydrogen can be distinguished by the fact that it burns with a yellow luminous flame, whereas sulphureted hydrogen burns with a bluish flame, and carbon dioxide will not support combustion, but, on the contrary, is a product of combustion.

When carbureted hydrogen gas is discovered ascending from water, the bottom of which is not covered with decaying vegetation, it is almost a certain sign that there is petroleum or bitumen somewhere in the underlying or adjacent formations.

If natural gas or bitumen is found upon the surface of shale, it is probable that the material ascended vertically through cracks in these rocks from porous strata below; while if it is found in connection with sandstones, it is probable that the material was derived from the porous sandstone itself. This is especially liable to be true if the sandstone has a steep pitch.

As a rule, deposits of bitumen or petroleum occur in porous formations overlaid by impervious strata, such as shales, slates, etc. Anticlines are more liable to contain such deposits, though they are not absolutely necessary to retain them, as at times portions of the underlying porous strata have been rendered impervious by deposits of calcium salts, silica, etc., and hence the petroleum or bitumen will be confined to the porous portions. Natural gas also occurs under similar conditions, but usually in anticlines only.

Construction of Geological Maps and Cross-Sections.—After the surface examination of a property is complete, the data should be entered on the best map procurable, or a map constructed. The scale depends on the size of the property, the complexity of the geological formation, the value of the property, and the material to be mined from it. The amount of work that it will pay to put on the survey will depend largely on the value of the property, more detail being justified in the case of high-grade properties. If a property 1,200 ft. × 3,000 ft. (the size of four U. S. mining claims) were to be surveyed and mapped with a scale of 1 in. equal to 100 ft., the map would be 12 in. × 30 in. A vein of strata 10 ft. wide on this map would appear as $\frac{1}{10}$ of an inch wide, which is about the smallest division that could be shown with its characteristic symbol; for greater detail, a larger scale, or larger scaled sheets of the most important portions of the deposit, will be necessary. If the geologist constructs the topographical contour map, he can take notes on the geology at the same time. When the boundaries of the property are being surveyed, certain points should be established, both vertically and horizontally, as stations in future topographical work. If the map is on government surveyed land, the government lines may be used for horizontal locations, but it will be necessary to determine the elevation of the different points. If the property is much broken, it is well to run a

few lines of levels across it, to establish points from which to continue the work. This work is usually done with a Y level and chain, the other details being subsequently filled in with a transit and stadia, the levels of the other points being taken either by using the transit as a level, by vertical angles, by barometric observations, or by means of a hand level. Where lines of levels are run across the property in various directions, it is best to run them in such a direction that they will cross the strike of the strata as nearly at right angles as possible, so that the profile thus determined may be used in constructing a cross-section. Sometimes, for preliminary work, simply a sketch map is all that may be necessary. All of the outcrops and exposures, together with their proper dip, should be entered on the map.

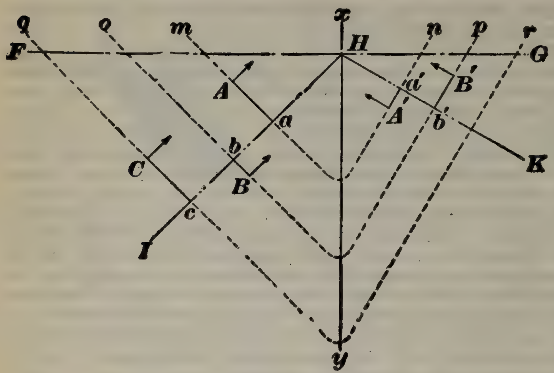


FIG. 5.

To Obtain Dip and Strike From Bore-Hole Records.—Before the results obtained from bore holes are available for use in map construction, the dip and strike of the various strata must be ascertained. The process, in the case of stratified rock, is as follows: If three holes were drilled, as at *A*, *B*, and *C*, Fig. 6, each intersecting a given bed, the strike and angle of dip of the bed may be obtained by reducing the results from the three holes to a plane passing through the highest point of intersection, which is at *A*. The hole *B* intersected the bed at the distance *Be*, and *C* at the distance *Cd* below the point *A*. By continuing the line *CB* indefinitely, and erecting two lines *Be* and *Cd* perpendicular to it, each representing the distance from the horizontal plane through *A* to the intersection of the strata, two points in the line *de* are obtained, which line intersects *CB* produced at *f*; *f* is one point in the line of strike through *A*. In order to find the angle of dip, the perpendicular *Cg* is dropped from the deepest hole *C* upon the line of

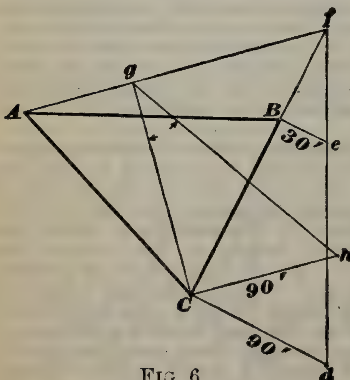


FIG. 6.

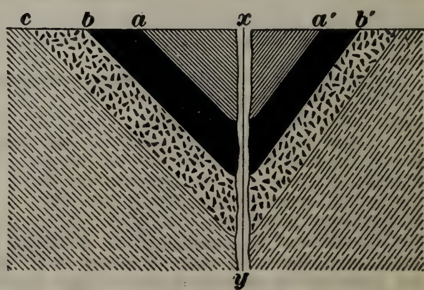


FIG. 7.

strike *Af*. The distance *Ch*, equal to *Cd*, is laid off at right angles to *Cg*, when the angle *Cgh* gives the maximum dip. The results obtained from bore holes may thus be reduced to such form that the dips can be projected on the surface to obtain the line of outcrop for each stratum. Bore holes also furnish data for constructing underground curves in cross-sections of stratified rocks, and in locating the probable outline of ore bodies in other formations.

Having recorded on the map all exposures, whether surface or those obtained from underground work, draw the line of strike and the outcrops. Also construct a cross-section. If the vein is perpendicular, the outcrop will be a straight course across the map. If the bed or seam is horizontal, the outcrop will correspond with the contour line. For beds or veins dipping at any other angle, results between these limits will be obtained.

If the property being examined is cut by synclines or anticlines, the dips will not all be in the same direction, and if there is a dip along the axis of the synclines or anticlines, the construction of the map will be considerably complicated. Fig. 5 represents a plan or map on which there is an axis $x\,y$ toward which the strata dip from both sides. Outcrops are indicated at A, B, C, A', and B', each having a dip in the direction of the arrow. The lines mn, op, qr are contours. If the cross-section were constructed on the line FG, perpendicular to the axis $x\,y$, the various beds or deposits would be cut at such an angle as to show a thickness in the cross-section greater than that which actually exists. In order to show the actual thickness for each seam, the cross-section must be taken along the line perpendicular to the strike of the strata, which, in the present case, is along the line IHK. In other words, the cross-section must be constructed in two parts. Where a general sketch is all that is necessary, a single cross-section with notes correcting the thickness of the seams may answer.

In order to construct the cross-section IHK, the outcrops A, B, C, A', and B' must be projected to the points a, b, c, a', and b', this projection being along their contours. If the points on the line of the intended cross-section were not upon the contour, it would be necessary to project them on the plane of the cross-section, as shown in the figure, and then from the dip of the strata and the difference in elevation to obtain a corrected point along the line IHK. The cross-section is constructed as shown in Fig. 7, each seam having its actual thickness as shown at the outcrop. If the upper surface of the cross-section is not a true profile of the surface, and the points are not projected in the plane on the cross-section. on this cross-section, according to their dips, there is considerable danger of exaggerating their thickness one way or the other.

On mine maps, the supposed course of the beds should be sketched in, subject to revision, as more data are brought out by later development work. Even in the case of stratified rocks, it is difficult to form a definite idea as to the underground conditions from surface indications, and, in the case of metamorphic or crystalline rocks, it is absolutely necessary to determine the underground conditions by drilling, or actual development work. If the property being examined is liable to become a large and valuable mining property, the original survey should be tied to monuments or natural landmarks, so that it can be checked by future observations, and these monuments or landmarks should become the basis of future and more careful mining surveys.

Some of the advantages of a careful geological examination of a property are that other materials of economic value would probably be discovered, if any should exist on the property; also, such an examination of the property gives information as to the drainage system of the country that may be of great advantage in laying out the mine, and future exploration by drilling or sinking can be done to better advantage after a careful surface examination.

Sampling and Estimating the Amount of Mineral Available.—In many cases, it is necessary to do some development or exploration work before fair average samples can be obtained. The samples as taken should fairly represent the material as it will be extracted. Such gangue as cannot be separated from the ore in mining, or slate that would be sold with the coal, should be included in the sample. When sampling any property it is well to divide the deposit up into blocks, and sample each one separately. The samples may then be assayed and an average obtained later, or the different samples may be mixed and an average assay obtained. The amount of material broken for sample may vary from a few pounds to many tons, depending on the nature of the material under consideration. Large samples may be reduced by shoveling (that is, taking a proportionate number of shovelfuls for the sample, as every third or fourth shovelful). After the sample has been partially reduced, the operation may be carried on by quartering, which may be described as follows:

The material is shoveled into a conical pile by throwing each shovelful on to the apex of the cone. After this, the cone may be reduced by

scraping it down with a shovel, passing slowly around it. If the amount of material is small, a flat plate may be introduced into the cone, and the pile flattened by revolving the plate. The pile is then divided into quarters by drawing lines across it. After this, two alternate quarters are scraped out and shoveled away, and the other two quarters are left as the sample. The process may be repeated until the block has been sufficiently reduced. In shoveling away the discarded portions, care should be taken to see that the fine dust under them is brushed away also, as they often contain fine and valuable mineral that would unduly increase the value of the resulting sample. When the sample consists of only a few pounds, it may be reduced by means of a riffle. Large samples consisting of several tons are sometimes sent to sampling works to be reduced by automatic sampling machines. If the property being examined is a mine in active operation, samples may be taken from the working faces, and also from cars, loading chutes, etc. Usually the samples from the face are kept separate from those from the cars and loading chutes, the latter being intended as a check on the former. In the case of ores of the precious metals, large samples are sometimes taken and used for mill runs.

Stock piles, or dumps, may be roughly sampled by taking pieces from intervals over the surface, being careful to obtain a fair average of coarse and fine material, and of rock and ore. These samples are quartered down and assayed, but if a close valuation is desired, it will be necessary to drive cuts or tunnels through the mass, and to take a certain amount, as every fifth or tenth shovelful, for the sample. When sampling dumps of fine material (as, for instance, tailings) it is possible to take samples from the pile by means of a drill, an auger 1 in. or 2 in. in diameter usually being employed for this purpose.

The human factor always plays a large part in the value of a sample as finally selected, and hence it should be taken by a man who has had considerable experience in this class of work. For this reason, it is best to employ a mining engineer. One not accustomed to sampling very rarely undervalues a property, owing to the fact that it seems to be human nature to pick up a rich piece of ore or coal, rather than the barren gangue material or slate.

When only surface exposures or shallow prospect openings are available, it is impossible to determine the amount of ore in sight, or to form more than a guess as to the size of the deposit. *It is not safe to count any ore in sight unless it is exposed on at least three faces.* Ore that is exposed on one or two faces can be counted as probable ore, while slight exposures can be counted only as chances indicated.

The amount of material available in coal deposits can be estimated much closer than in the case of ores. If a seam is penetrated by a number of bore holes, or by workings extended over a considerable area, it is fair to estimate that the material will run practically as exposed for a considerable area; but especially in the case of bituminous coal, it is a comparatively easy matter to form some estimate as to the amount of material available.

When dealing with ores, it is impossible to form reliable estimates, owing to the fact that horses or other masses of rock may be exposed at any point, and the ore bodies themselves are usually very irregular, hence it will be necessary to do careful blocking out before making any estimates.

When estimating the amount of mineral available, only that portion which can actually be removed in stoping should be counted, and if the seam is so narrow that it is necessary to break material from the walls, or if there are masses of country rock that have to be removed with the ore, the expense of removing them should be estimated and deducted from the value of the ore.

DIAGRAM FOR REPORTING ON MINERAL LANDS.

The following diagram will be useful as a guide in making out a report on a mining property:

1. SITUATION AND SURROUNDINGS.
   - 1. Name.
     - 1. Location, if on surveyed land.
     - 2. Nearest town or village.
     - 3. Mineral district.
     - 4. County, state, or territory.
   - 2. Distance and direction from one or more points.

DIAGRAM FOR REPORTING ON MINERAL LANDS—(*Continued*).

- 2. TOPOGRAPHY.
  - 1. Hills or mountains.
  - 2. Character of surface, vegetation, and timber.
  - 3. Streams and water supply.
  - 4. Elevations.

- 3. GEOLOGY.
  - 1. Structure.
    - 1. Rocks.
      - 1. Stratified.
      - 2. Crystalline.
      - 3. Igneous.
    - 2. Axes.
      - Anticlines or synclines.
    - 3. Faults.
      - 1. Number.
      - 2. Strike.
      - 3. Dip.
      - 4. Throw.
    - 4. Dikes.
      - 1. Number.
      - 2. Strike.
      - 3. Dip.
      - 4. Filling.
      - 5. Throw.
    - 5. Horses.
      - 1. Number and size.
      - 2. Location.
      - 3. Material.
  - 2. Geological period.
  - 3. (*a*) Coal beds.
    - 1. Number.
    - 2. Thickness.
      - 1. Reported.
      - 2. Measured.
      - 3. Average.
      - 4. Uniformity.
        - 1. Reported.
        - 2. According to measurement.
  - or
  - (*b*) Ore bodies.
    - 1. Veins.
      - 1. Number.
      - 2. Character.
      - 3. Strike.
      - 4. Dip.
      - 5. Width.
        - 1. Maximum.
        - 2. Average.
      - 6. Vein filling.
      - 7. Ore chutes.
      - 8. Walls.
      - 9. Throw of walls.
    - 2. Beds or lenses.
      - 1. Number.
      - 2. Walls.
      - 3. Strike.
      - 4. Dip.
      - 5. Length.
      - 6. Height.
      - 7. Maximum width.
      - 8. Average width.
  - 4. (*a*) Quality of coal, specimens, appearance in mine, in cars, benches.
    - 1. Color, external, powder.
    - 2. Luster.
    - 3. Clearness from clay or sand, shale.
    - 4. Sulphur.
    - 5. Resin.
    - 6. Firmness, size of lumps, air slaking.
    - 7. Cleavage or fiber.
    - 8. Coking.
    - 9. Color of ashes.
    - 10. Use: Gas, steam, domestic, forge, metallurgy.
    - 11. Analyses or assays.
  - or
  - (*b*) Ore.
    - 1. Shipping.
    - 2. Concentrating.
    - 3. Metals or minerals.
    - 4. Gangue.
    - 5. Impurities.
    - 6. Assays or analyses.

DIAGRAM FOR REPORTING ON MINERAL LANDS—(*Continued*).

- 4. MINING.
  - 1. History.
    - 1. Dates of opening, abandoning, reopening, number of mines and names.
    - 2. Ownership.
    - 3. Superintendence.
  - 2. Mine.
    - 1. Shaft, slope, or tunnel.
    - 2. Extent of workings.
      - 1. Total depth.
      - 2. Depth below water level.
      - 3. Number of levels.
      - 4. Extent of levels.
    - 3. Water pumps, size, and kind, water cars, number and size, natural drainage.
    - 4. Ventilation, natural, furnace, fan (forcing or drawing out), sufficient or insufficient.
    - 5. Lighting, system used.
    - 6. Powder, kind and grade used.
    - 7. Explosive or noxious gases.
    - 8. Coal-cutting machines and power drills.
    - 9. (*a*) Mode of working, holding under, shearing, blasting, or wedging.
      - (*b*) Mode of working.
        - 1. Underhand stoping.
        - 2. Overhead stoping.
        - 3. Filling.
        - 4. Caving.
        - 5. Rooming with or without timber.
        - 6. Square sets.
    - 10. Rooms, or stopes, pillars, dimensions, and general plan.
    - 11. Timbering, timber trees.
    - 12. Roof, or hanging wall, strong or weak, air slakes or not.
    - 13. Floor, or foot-wall, hard or soft, creeps or not.
    - 14. Roads, rails, and cars.
    - 15. System of underground tramming.
      - 1. Men.
      - 2. Mules.
      - 3. Electricity.
      - 4. Compressed air.
      - 5. Wire rope.
      - 6. Chain.
      - 7. Locomotive.
    - 16. System of hoisting.
      - 1. Cage.
      - 2. Skip.
      - 3. Cars.
- 5. MAPS AND DRAWINGS.
  - 1. Of the whole region.
  - 2. Of the underground workings.
  - 3. Sections.
    - 1. Cross.
    - 2. Longitudinal.
    - 3. Columnar.
      - 1. General.
      - 2. Coal bed or other deposit.
  - 4. Buildings, works, or machinery.
  - 5. Explanation.
    - 1. Scale.
    - 2. North line, magnetic variations.
    - 3. Date.
    - 4. Maker.
    - 5. Can buy, take, borrow, or have copied.
- 6. CONCENTRATION.
  - 1. Hand picking.
  - 2. Cobbing and picking.
  - 3. Magnetic.
  - 4. Mechanical.
    - 1. Wet.
    - 2. Dry.

DIAGRAM FOR REPORTING ON MINERAL LANDS—(*Continued*).

- 7. COKE OVENS.
  - 1. History, ownership, etc.
  - 2. Number.
  - 3. Character of ovens.
  - 4. Dimensions.
  - 5. Construction, materials, etc.
  - 6. Operations.
    - 1. Charge, quantity, etc.
    - 2. Working.
    - 3. Discharging, quenching.
  - 7. Repairs.
  - 8. Quality of product. (Assays, if any.)
  - 9. Disposition of by products.
- 8. METALLURGICAL WORKS AND TREATMENT OF ORE.
  - 1. Roasted.
    - 1. In heaps.
    - 2. In stalls.
    - 3. In kilns.
    - 4. By mechanical calciners.
    - 5. Number and dimensions of roasters.
  - 2. Smelted.
    - 1. In shaft furnace to
      - 1. Base bullion.
      - 2. Matte.
      - 3. Metal.
      - 4. Number and dimensions of furnaces.
    - 2. In reverberatory furnace to
      - 1. Metal.
      - 2. Matte.
      - 3. Number and dimensions of furnaces.
    - 3. In retorts to
      - 1. Metallic zinc.
      - 2. Mercury.
      - 3. Number and size of retorts.
- 9. DISPOSITION OF PRODUCT.
  - 1. Shipped.
    - 1. As mined to
      - 1. Smelter.
      - 2. Concentrator.
      - 3. Sampling works.
      - 4. Jobber at ———
    - 2. As concentrates or coke.
      - 1. Smelter or furnace.
      - 2. Sampling works.
      - 3. Jobber at ———
    - 3. Metal or matte to
      - 1. Refinery.
      - 2. Smelter.
      - 3. Jobber at ———
  - 2. Shipment.
    - 1. Distance.
    - 2. Roads.
    - 3. Railroads.
    - 4. Navigation.
- 10. STATISTICS.
  - 1. Production.
    - 1. Capacity.
    - 2. Actual.
      - 1. Daily, weekly, or monthly, in tons.
      - 2. Yearly in tons.
      - 3. Average.
  - 2. Labor.
    - 1. Whole number of workers.
    - 2. Number of workers in each class.
    - 3. Number of horses or mules.
  - 3. Prices.
    - 1. Timber.
    - 2. Tools.
    - 3. Fuel.
    - 4. Oil.
    - 5. Powder.
    - 6. Labor.
      - 1. Day, different classes.
      - 2. Contract or piece, yard or ton.
    - 7. Carriage.
    - 8. Local sales of product.
    - 9. Value of plant.
      - 1. Machinery.
      - 2. Buildings.
      - 3. Roads, tracks, etc.
      - 4. Rolling stock.
      - 5. Supplies.

DIAGRAM FOR REPORTING ON MINERAL LANDS—(*Continued*).

- 11. SURFACE PLANT.
  - 1. Power plant.
    - 1. Boilers.
    - 2. Waterwheels.
    - 3. Air compressors.
    - 4. Steam and gas engines.
    - 5. Electric plants.
  - 2. Shops.
    - 1. Smith's shop.
      - 1. Power for.
      - 2. No. of forges.
      - 3. Steam hammers.
      - 4. Other tools.
    - 2. Carpenter shop.
      - 1. Power for.
      - 2. Saws.
      - 3. Lathes.
      - 4. Other machines.
      - 5. Benches and vises.
    - 3. Machine shop.
      - 1. Power.
      - 2. Lathes.
      - 3. Planers.
      - 4. Shapers.
      - 5. Drill presses.
      - 6. Other tools.
      - 7. Benches and vises.
  - 3. Powder houses.
  - 4. Offices.
  - 5. Dry or change houses.
  - 6. Storehouses.
  - 7. Boarding and dwelling houses.
  - 8. Stables.
  - 9. Shaft houses.
  - 10. Tipples.
  - 11. Pockets or ore bins.
  - 12. Company store.
  - 13. Timber yard and plant for preparing timber.
  - 14. Water.
    - 1. City or commercial service.
      - 1. Quality of water.
      - 2. Sufficient or insufficient.
      - 3. Pressure.
    - 2. Company service.
      - 1. Quality of water.
      - 2. Sufficient or insufficient.
      - 3. Gravity system.
      - 4. Pumping system.
        - 1. Direct.
        - 2. Reservoir or stand pipe.
  - 15. Lighting.
    - 1. Character.
      - 1. Gas.
      - 2. Electric.
    - 2. Origin.
      - 1. Commercial plant.
      - 2. Company plant.
    - 3. Sufficient or insufficient.
  - 16. Hoisting or winding plant.
    - 1. Steam engines.
    - 2. Compressed-air engines.
    - 3. Oil or gasoline engines.
    - 4. Electric motors.
    - 5. Water motors.
  - 17. Surface transportation.
    - 1. Railroad.
      - 1. Gauge.
      - 2. Total length.
      - 3. Size of cars.
      - 4. No. of cars.
      - 5. Power used.
      - 6. No. of motors.
    - 2. Wagon roads.
      - 1. Character and surface of.
      - 2. Length.
      - 3. No. of wagons and teams.
    - 3. Traction engines.
      - 1. Size and capacity of.
      - 2. No. of wagons for.

DIAGRAM FOR REPORTING ON MINERAL LANDS—(*Continued*).

12. MISCELLANEOUS.

13. CONCLUSIONS.
    - 1. Yearly income, last year, or for any year.
        - 1. Gross.
        - 2. Net.
    - 2. Average cost per lb., or ton of material.
    - 3. Merits of property.
        - 1. Deposits of value.
            - 1. Quality of ore or product.
            - 2. Amount of ore or material in sight.
                - 1. Gross.
                - 2. Net.
            - 3. Value of material in sight.
        - 2. Value of plant and works.
    - 4. Advice.
        - 1. Mining.
            - 1. Continue present system.
            - 2. Change system to ——.
        - 2. Disposition of product.
            - 1. Ship as mined.
            - 2. Concentrate, or coke and ship.
            - 3. Smelt and ship.
    - 5. Local considerations.
        - 1. Troubles.
        - 2. Labor.
        - 3. Supplies.
        - 4. Climate.
        - 5. Shipment facilities.
        - 6. Markets.

OPENING A MINE.

The location of the surface plant and the mine opening depend on the formation of the deposit primarily, and secondarily on the facilities for transporting the product to market. It is impossible for one not on the ground, and unfamiliar with natural or railroad transportation facilities in the neighborhood, to give an idea as regards the second consideration. In regard to the first consideration, the following observations will be found of value:

When the seam or vein outcrops within the limits of the property and is flat, a water-level drift is the best method of opening it. If it has any considerable inclination, it should be opened by a slope, or by a tunnel driven across the intervening measures. Where the deposit has an inclination of but from $\frac{1}{10}$ of 1° to $1\frac{1}{4}$°, the water-level drift is generally used, and the main-haulage entry is opened at the lowest accessible point on the outcrop, which insures free drainage and a favorable grade for haulage. When the outcrop dips into the hill, the drift is usually commenced a few feet below the outcrop terrace, and driven on a slight up grade until the normal dip is reached.

When the inward dip is too strong, the better plan is to sink a shaft in the center of the basin, provided the depth is not too great and the amount of water to be pumped is comparatively small. If the inward dip to the center of the basin does not exceed a total of 25 ft. difference in level, a drift may be used and drainage be effected by a siphon.

Water-level drifts are only profitable where the inclined seam is exposed in ravines or gorges eroded across the strike of the measure, or where the vein can be reached by a short tunnel from the surface to the seam across the measures. This is often the case when the seam dips with the hill, but when the dip is against the hill, the tunnel is generally a long one. While the expense of operating a mine opened by a long tunnel is less than one opened by a slope or shaft, owing to cheaper drainage and haulage, when the coal above water level is exhausted the tunnel is almost worthless. When the seam is inclined and is accessible at no point along its outcrop low enough to furnish sufficient lift or breast length, it should be opened by a slope or shaft. Or, if the seam is flat and does not crop on the tract, a shaft is the only method of working it, unless it lies so near the surface that it can be stripped.

Where a seam has a dip of 20° or more, and is brought close to the surface by an anticlinal axis or "saddle," a "rock slope," or, in other words, a tunnel dipping the same as the seam may be started from the surface, and, when the seam is reached, may be continued to the desired depth in the

seam. In sinking slopes for coal mines, it is customary to sink an airway alongside of and parallel with the slope, with a pillar of about 10 yd. between. The slope for coal mines is usually sunk so that there is a "lift" of from 100 to 110 yd., and then gangways are turned off on each side. The term "lift" in this connection means the length on pitch that breasts or rooms, driven at right angles to the gangway, can be driven in good coal. Subsequent lifts are usually from 80 to 100 yd. long.

Opening Up a Gold Mine.—The following description of the method of opening up a gold mine, by Mr. S. A. Josephi ("Mines and Minerals," February, 1900), will also apply in general for the opening of any inclined narrow ore deposit: The equipment for the top of shaft for the preliminary work consists of three pieces of timber, either sawed or rough hewn, 12 to 16 ft. long, 8 to 10 in. in diameter, arranged as a tripod; they should be strongly bolted together, a pulley hung from the center, through this a rope passed with a bucket fastened to the end entering the shaft, and a horse hitched to the other end. This equipment is called a *whip*, and is sufficient for the first 100 ft. in depth. In locating the shaft, care should be exercised in placing it where there is ample dump, or ground for waste or valueless vein matter. Should the character of the surface not admit of sufficient ground for this purpose, have collar (or top) of shaft elevated 10 or 12 ft., and throw waste around the outside of same until filled up solid.

The timbers should be square sets made of rough or square timbers, preferably the latter, 8 in. × 8 in.; divide the shaft into two compartments 4 ft. × 4 ft. each, one for the bucketway, the other for the ladderway. Where air is bad, board up the ladderway to aid the circulation. The sets should be not less than 4 ft. and not over 6 ft. apart, in the clear.

Sink on the dip of the vein, and keep a careful record of the location, width, and value of ore body, until the depth of 100 ft. is attained; here place station sets 8 ft. high, start levels each side of shaft, and, if there is water in the shaft, a sump 16 ft. to 30 ft. deep should be sunk. The sump should be built in the same manner as the shaft, so that it will serve as a continuation of same when greater depth is wanted.

Levels should be run on both sides of the shaft sufficiently long to determine length of the ore chute, and also to determine the existence of other ore chutes in the vein. This development work should be an indicator of the strength, value, and permanence of the property; it is now ready for another examination by competent authorities, to determine the above conditions. Should their verdict be favorable, continue the shaft to the depth of an additional 100 ft.; if water is found in but small quantities, this can best be done by replacing the whip with a whim; this runs by the same horsepower, costing in the neighborhood of $100. It is well adapted to put the shaft down 250 ft.

When the shaft is down 200 ft., start levels as at the 100-ft. depth, provide sump, and drift both ways upon the vein, proving up ore bodies as before.

Thus far the cost has been slight. The shaft, including timbers, supplies, and contingent expenses, should not cost over $20 a foot, a total of $4,000; the drifts $6 a foot, say 200 ft. each way from shaft on both levels, a total of 800 ft. or $4,800; total, $8,800, less amount received from mineral extracted in sinking and drifting, which is usually small.

Now it is to be decided what further amount the owners are willing to expend, and how extensively they desire the mine opened up before the actual extraction of ore is to commence. We will put the depth of shaft at 500 ft., the drifts the full length of the claim, usually 1,500 ft.

For this purpose, a shaft house should be built, say 40 ft. × 60 ft., with ore house, say, 40 ft. × 40 ft. The equipment should be a 40 H. P. engine and a 60 H. P. boiler (if a large flow of water is encountered, an additional boiler and pump must be provided), the shaft continued to the above stated depth, and levels extended at each 100 ft. It will also be advisable to make upraises at the farthest point practical from the shaft, on each side, connecting each level with the other, and extending to the surface. These upraises should be made in ore, and are valuable both for ventilation and escape for men, in case of accident to or near the shaft. They should be furnished with ladders. The machinery, shaft house, and skip, with which all incline shafts should be equipped, will cost about $4,500. The additional 300 ft. of shaft, including contingent expenses of engineers, fuel, etc. will cost $40 a foot, or $12,000; the drifts, $6 a foot. The upraises, being on ore, should pay for the labor.

It is prudent to estimate the cost of thoroughly opening up a gold mine to

be between $40,000 and $50,000, which fact probably originated the remark that "it takes a gold mine to make a gold mine." This is practically true, and no one should attempt to engage in the mining business, as a business, without both money and a willingness to use it. More failures can be attributed to insufficient capital for development than to any cause save mismanagement.

SHAFTS.

Shafts and tunnels may be, *first*, temporary, or those that are simply driven for exploration purposes, and are not to be used for any great length of time; *second*, permanent, or those that are driven for a specific purpose and usually have a definite predetermined capacity.

Form of Shaft.—In the United States, shafts are usually square or rectangular in form. This is largely due to the fact that timber is used in lining such shafts. In Europe, round or oval shafts are frequently employed with a lining of brick, iron, or masonry.

Compartments.—The number of compartments in a shaft and their arrangement depends largely on the use to which the shaft is to be put; also on the number of shafts at the property, and the depth of the shaft. Where the material to be removed is comparatively near the surface, it is usually cheaper to sink a number of 2- or 3-compartment shafts than it is to tram all the ore to one large shaft; while, in the case of very deep mines, large 4- or 6-compartment shafts are sunk, and the underground haulage extends over a greater area. When the shafts are lined with timber, a stronger construction can be obtained by placing the compartments side by side, as shown in Fig. 1, than by placing them in the solid block, as shown in Fig. 2. When a body of material comparatively near the surface is being removed through a number of shafts, 2-compartment shafts are frequently employed, both compartments being used for hoisting, and separate shafts being provided for the pump column and ladderways. This reduces both the size of the shaft and the timbering necessary, and also does away with the special danger from fire that always exists when there is a ladderway in the shaft, for it is always difficult to fight fire in these special compartments.

FIG. 1.

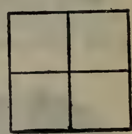


FIG. 2.

Shaft Sinking.—As a general thing, the loose material or wash above bed rock is not thick enough to cause any serious trouble, and ordinary cribbing of heavy timber or a masonry curbing is sufficient. But when the surface is very thick or loose, and runs like quicksand, considerable difficulty is experienced. The general method of overcoming this difficulty in the past was to at once divide the shaft into the required number of compartments by heavy timbers alternating or placed "skin to skin," which had the effect of bracing the cribbing against the lateral pressure of the loose material. This method is effectual where the wash will remain solid or stand long enough to allow the timbering and cribbing to be put in. But when the surface is thick, loose, or watery, or of quicksand, some one of the following special methods of sinking must be adopted:

Quicksand .... {
"Forepoling."
"Metal linings." (Forced down without the use of compressed air.)
"Pneumatic" method. (Limited to about 100 ft. in depth.)
"Poetsch" process. (Freezing method.)
}

Rock (hard or soft, but very wet) .... { "Kind-Chaudron" method.

Rock (hard or soft, but not very wet) --- { "Continuous," or "Long-Hole," method.

Size of Shafts.—Shafts vary greatly in size, depending on the number of compartments desired and the size of the compartments. For coal mines, they are generally from 10 to 12 ft. wide inside of timbers, and each

compartment is from 6 to 7 ft. wide inside the guides. This would make the outside dimensions of a double-compartment shaft about 13 to 15 ft. wide, 17 to 18 ft. long, and a triple-compartment shaft from 24 to 25 ft. long. Shafts at metal mines are generally smaller than those at coal mines, but the practice in different localities varies so that it is impossible to give general dimensions that would be of value.

The table on opposite page gives the dimensions of a few well-known shafts in different localities.

Forepoling.—When the ground is so bad that it will not stand for several days between excavation and the completion of the lining, it becomes necessary to carry the timber to the bottom of the work. This may be accomplished by using square-set shaft timbering and driving laths, or forepoling behind the timber so as to keep the soft material from running into the opening. The advantages of forepoling are that, if the shaft is being lined with square sets, it can be commenced at any point, and, if the ground is not too bad, the work can be continued by this means until solid material is encountered. When the ground is particularly bad, it may become necessary to use breast boards, which are simply boards braced against the bottom of the shaft so as to keep the material from rising into the opening, only one board at a time being removed while the material behind it is excavated.

In particularly bad ground, where breast boards have to be used, the progress made is very slow. After the shaft has been put down by forepoling, it is sometimes very difficult to repair or replace the lining. When the forepoling method is employed in quicksand, there is considerable risk of losing the shaft altogether, owing to sudden rushes or "boils" of the material that throw the timbering out of line and fill up the shaft.

Metal Linings Forced Down.—Metal linings forced down without the use of compressed air are rarely resorted to, though in some cases they have been quite successful. If the formation contains but few boulders, it is sometimes possible to force the lining down by flushing out the material from the inside with jets of water. At other times, men enter the shaft and excavate the material as the work progresses.

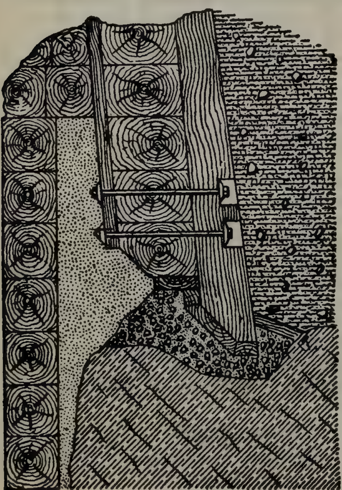


FIG. 3.

The **pneumatic method of shaft sinking** was developed from the system in use for putting down foundations for bridge piers. At the bottom of the shaft there is a small chamber called a caisson, in which a sufficient air pressure is maintained to exclude the water at all times. The shaft lining is built on above this chamber, and gradually forced down into the soil. Men enter the chamber and excavate the material from under the caisson as it descends.

By this method the sinking commences at once and is continued without interruption until the lining is completed to bed rock, to which the lining is joined, as shown in Fig. 3. An air compressor, which is subsequently used, is the only auxiliary machine necessary, while in the freezing process an ice machine is required.

It is best to use electric lights in the caisson; hence, it may be necessary to install a small dynamo if the company does not have an electric-light system in operation. In the pneumatic system, the bottom of the shaft is always exposed to view, and the workmen know when they reach a solid foundation; while, in the freezing process, it is sometimes difficult to tell to what depths the pipes should be sunk so as to reach below any fissures or seams in the bed rock. In the pneumatic process, the fine material is aspirated out of the caisson by the air pressure. The pneumatic process is limited to a depth of about 100 ft., as it is impossible for men to work under a greater air pressure than that which corresponds to about 100 ft. of hydrostatic pressure.

By the **freezing process**, pipes are sunk in the ground about the area to be frozen, as a rule, not more than 3 or 4 ft. apart. The lower ends of the pipes

TABLE OF WELL-KNOWN SHAFTS.

Name.	Location.	Material Mined.	No. of Compartments.	Size of Hoisting Compartments.	Size of Shaft Over All.	Depth. Feet.	Remarks.
No. 5 Shaft	Wilkes-Barre, Pa.	Anthracite	5	7′ 6″ × 12′	12′ 0″ × 52′ 0″	1,039	2 hoistways, 1 pumpway, upcast 12′ × 14′ 10″, downcast 12′ × 12′.
Hazleton Shaft	Hazleton, Pa.	Anthracite	5	7′ 6″ × 12′ 6″	37′ 0″ × 13′ 10″	326*	Pumpway 3′ × 12′ 6″.
Exeter Red Ash	Exeter Boro., Luzerne Co., Pa.	Anthracite	6	7′ 6″ × 12′ 6″	46′ 2″ × 13′ 10″	578	Pumpway 20″ × 12′ 6″, airway 9′ 6″ × 12′ 6″.
Leith Mine	Uniontown, Pa.	Bituminous	4	6′ 10″ × 10′ 4″	12′ 4″ × 23′ 10″	282	2 hoistways, 1 pumpway, 1 airway.
General Type	Pa. Bituminous Region	Bituminous	3	7′ 4″ × 10′ 4″	12′ 4″ × 25′ 6″	50 to 550	2 hoistways, 1 airway.
Centennial Eureka	Eureka, Utah	Gold, Silver, Copper, Lead	3	4′ 2″ × 4′ 2″	5′ 6″ × 12′ 8″	1,610	1 manway 2′ 4″ × 4′ 2″.
Ontario	Park City, Utah	Silver	3	4′ 6″ × 5′ 0″	7′ 0″ × 20′ 0″	1,500	
Red Jacket	Calumet, Mich.	Copper	6	6′ 3″ × 7′ 0″	25′ 0″ × 15′ 6″	4,900	
Tamarack	Tamarack, Mich.	Copper	5	7′ 2″ × 5′ 2″	29′ 2″ × 8′ 10″	4,615	Depth when completed.
Anaconda	Butte, Mont.	Copper	3	4′ 6″ × 5′ 0″	20′ 4″ × 6′ 8″		Still sinking (over 1,000 ft.).
Butte and Boston	Butte, Mont.	Copper	3	4′ 0″ × 4′ 6″	18′ 4″ × 6′ 2″		Still sinking.
Hamilton	Iron Mountain, Mich.	Iron	6	4′ 8″ × 7′ 0″	23′ 4″ × 9′ 0″	1,460	2 compartments 4′ 8″ × 6′ 4″ for men, 2 for pipes 4′ 8″ × 2′.
Salisbury	Ishpeming, Mich.	Iron	3	5′ 6″ × 7′ 0″	22′ 0″ × 9′ 0″	1,400	Inclined, still sinking.
Fayal Iron Co.	Eveleth, Minn.	Iron	3	5′ 8″ × 5′ 0″	19′ 8″ × 6′ 8″		Inclined 66° from the horizontal.
Consolidated California and Virginia Mining Co.	Virginia City, Nev.	Silver, Gold	3	5′ 4″ × 4′ 6″	19′ 0″ × 7′ 8″	2,500	Pumpway 5′ 4″ × 6′.
Virginius	Revenue Mt., Colo.		2		8′ 0″ × 4′ 0″†	1,400	
Isabella	Cripple Creek, Colo.	Gold	3		13′ 6″ × 4′ 6″	940	
Average for Large Mines in	Colorado		3		15′ 0″ × 5′ 0″; 13′ 6″ × 5′ 0″		
Parker Shaft	Franklin Furnace, N. J.	Zinc	3	5′ 0″ × 7′ 0″	19′ 1″ × 7′ 2″	980	See "Mines and Minerals," Vol. 20, page 481.
General Type	Joplin, Mo.	Zinc	1	5′ × 5′ to 6′ × 9′	5′ × 5′ to 6′ × 9′		

*Depth completed, 1,150 ft. †In the clear.

are sealed or closed, and an inner tube introduced so that a freezing mixture may be caused to circulate down through the inner tube, and up through the outer tube. This freezing mixture may be either liquid ammonia gas, which is allowed to expand in the outer tube, or it may be a solution of calcium chloride that has previously been reduced to a very low temperature by means of an ordinary refrigerating machine. The circulation is maintained in the pipes until the ground between them is frozen solid, after which the work may be continued as though the formation were solid rock, the material being blasted and hoisted in buckets. The freezing process may be applied to any wet formation, whether hard or soft, while the pneumatic process is applicable only to soft formations. The freezing process may be carried to practically any depth. As a rule, the freezing pipes are never sunk inside of the shaft area.

The **Kind-Chaudron method** is applicable only to round shafts, and is suitable for shafts passing through very wet and at the same time comparatively soft formations. The excavation is carried on by means of a large set of boring tools armed with steel teeth, and operated in a manner similar to that employed in drilling wells by the percussive system. First, a pit or shaft 4 or 5 ft. in diameter is drilled; this is followed by a reaming bit that enlarges the hole to the desired diameter, or the work may be accomplished in three stages by using two reaming bits. The material removed by the first bit is hoisted out by means of a sand bucket, or sludger, while that removed by the succeeding tools is hoisted out by buckets that are placed in the bottom of the first pit and kept there while the tools are in operation. No water is pumped from the shaft while it is being excavated or lined, and hence practically all the tendency that the sides would have to cave is removed. After the shaft has been excavated down to and into a solid formation, it is lined by lowering cast-iron tubbing into the hole and making a tight joint against the bottom by means of an expansive packing that is forced out by the weight of the tubbing, or lining. After the lining is in place, the space between it and the sides of the excavation is filled with cement. When the cement is thoroughly hardened, the water is pumped from the inside of the lining, and men descend and examine the joint at bed rock. In this method, no workmen enter the shaft until it is lined through the troublesome formation.

Long-Hole Process.—The long-hole process consists in the drilling of a series of diamond-drill holes over the area of the proposed shaft, then filling the holes with sand, after which the work progresses by removing the first 5 or 6 ft. of sand from the holes in the interior of the shaft, charging these holes with explosives, and firing them by electricity. Next, the holes around the boundary of the shaft are charged and fired in the same manner, and the process is continued until the bottoms of the diamond-drill holes are reached. This method is especially applicable to work in hard rock, where great speed in sinking is desired, for all the drilling is accomplished at one operation, after which the sinking progresses by simply cleaning out the drill hole and blasting the material.

General Comparison of Methods of Shaft Sinking.—Where a shaft is sunk by forepoling, it is usually made rectangular in form. The pneumatic method may be used for either round or rectangular shafts, and the lining may be either of metal or wood. The freezing process may be used for either round or rectangular shafts, and the lining may be either timber, metal, or masonry, as the entire opening can be left open until the solid rock is reached, when the lining can be built upon it. The Kind-Chaudron method is applicable only to round shafts, on account of the fact that the hole is bored. The long-hole process is applicable to either round or rectangular shafts, but was originally introduced for sinking rectangular shafts.

Sinking Head-Frames.—Head-frames of very simple form are used for sinking. The skeleton of the frame is formed of heavy squared timber (10″ × 10″ or 12″ × 12″) mortised and pinned together, and braced by diagonal braces. A good height from the surface to the center of the sheave is from 20 to 25 ft. The sheave should be from 6 to 8 ft. in diameter. The sinking bucket should be of boiler iron, or of heavy hard wood strengthened by iron bands, about 3 ft. in diameter at the top by from 2½ to 3 ft. deep. It should be suspended by a handle pivoted a trifle below the center, and it should have a pin on the rim of the bucket that will hold it in an upright position when a loose ring on the handle is slipped over it. A chain fastened to the top of the head-frame, with a hook on its loose end, is suspended so that, when hanging plumb, it is over a chute leading to the dump car. As the bucket is

hoisted out of the shaft, this chain is attached, and the engine reversed. The bucket swings over the chute, the ring holding it upright is knocked off the pin, and the rock is dropped into the chute. Rocks too large for the bucket are suspended in chains and are hoisted in that way, and removed on a truck that runs on a track inside of the head-frame, the gauge of which is sufficiently wide to give plenty of clearance for the bucket.

Sinking Engines.—Most shafts and slopes are sunk with old engines, or else by engines especially designed for such work, and so constructed that they can easily be moved from place to place. In some cases where an old engine can be readily had, it is set up on temporary timber foundations and used until the shaft or slope is finished, when it is replaced by the permanent engines, and the old one is dismantled and disposed of to the best advantage.

Tools.—The old method of hand drilling is still adhered to in many instances, but it is gradually giving way to machine drilling, especially in deep shafts. When properly managed, the work is done much more rapidly and economically by the several excellent types of rock drills now on the market. They are constructed in a variety of shapes by the makers, and there are so many convenient accessories in the shape of fittings, etc. that all contractors prominent in the various coal fields possess one or more of their favorite type of drills. These drills are run either by compressed air, steam, or electric power, and in large shafts two are usually employed, so that work may not be delayed by a breakdown of one drill. The center or one side of the shaft is usually kept in advance of the rest, so as to furnish a sump for the collection of the water. The holes are drilled from 3 to 6 ft. apart, and the depth varies with the character of the rock. When a sufficient number of holes are drilled, the drill is removed, and a cartridge made of dynamite, dualine, or some other form of high explosive is tamped in each hole. These are all fired simultaneously by an electric battery, detonating caps being placed in each charge.

To keep the shaft the required shape, if rectangular, a plumb-bob is suspended in each corner, either from the flooring on top, or from a beam laid across the cribbing, and these guide the miner in squaring the corners and sides. If the shaft is a circular one, a plumb-line is let down in the center, from time to time, and a rod cut the exact radius is revolved around it. If it strikes the rib, the miner knows that at that point the shaft is not true.

Drainage and Ventilation.—When only a small amount of water is encountered while sinking, the best plan is to allow it to collect in a depression and bail it from there into the bucket, hoisting it the same as the rock. Where the water is excessive in quantity, a steam pump is necessary. All the leading pump works make pumps especially designed for sinking purposes, and it is not in the province of this work to mention the advantages possessed by one over the other.

When the shaft is of moderate depth, a fire burning in one corner will supply ample ventilation. To rapidly clear away smoke, a good plan is to burn a bundle of straw or shavings in one end of the shaft, and throw a couple of buckets of water down the other end. When the shaft is very deep, or when the sectional area is small, ventilation is produced either by a steam jet, or by a small fan turned either by steam or by hand. In some cases, a fire is used that draws into a board pipe.

Speed and Cost of Sinking.—Any attempt at a general estimate regarding the speed and cost of sinking is impossible, for many reasons appreciated by the practical miner. Shafts vary so much in size, and in the character of the material through which they pass, that even if there were no other items to be considered, a general estimate could not be made. But if the ground is pretty well known, and the sectional area and the depth given, the experienced contractor knows how much he can drive in a given time, and he can consequently form a good estimate for each separate shaft. The range of cost is so great that it may be anywhere from $1 to $10 per cubic yard of material excavated.

Slope Sinking.—A slope is an inclined plane driven down on the bed of the seam, and is generally through coal or ore, though sometimes they are driven through rock across measures to cut the seam that cannot be conveniently worked by a slope. In the latter case, it is merely an "inclined tunnel." In the former it might be termed an "inclined gangway."

A slope and an inclined plane, when mentioned hereafter, will mean an inclined opening *in coal or ore*, used as a passageway for mine cars.

When the location of the slope has been decided on, erect a temporary

sinking plant; an old engine is generally used. For a short distance, varying with the nature of the ground, but usually ranging from 10 to 20 ft. on the pitch, an open cut is made, and the earth, rock, or crop coal is thrown out by hand. As soon as sufficient cover is reached, the work of undermining and timbering is commenced, and at the same time a double or single track is laid, so that the material can be taken out in a car or self-dumping skip. When the latter is used, the track is continued up a trestle some distance above the surface, and a head-sheave so placed as to draw the skip up the required distance and dump the material in a chute beneath the trestling.

The width of the slope depends on the size of the cars and the number of compartments. The most common arrangement is to divide the slope into three compartments; two large ones for hoistways, and a smaller one for pump rod, column pipe, steam pipe, and traveling way. This last is also used as an airway while sinking is going on.

In some instances, slopes have but one hoistway, laid with three rails and a turnout at the middle of the hoist, and some have single track with a central turnout. This may be economy in first cost, but is not in the long run. Collisions are apt to occur, and the breaking of a rope or the falling of coal from an ascending car is apt to cause more damage than when two compartments are used.

When several lifts are simultaneously worked, a single-track slope is used; but unless the pitch is light and several cars can be hoisted at once, this method produces a comparatively small output.

When the dip of a slope is under 40°, the height of the slope should be about 7 ft. in the clear. When the slope dips more than 40°, unless self-dumping skips or gunboats are used, a cage is necessary, and then the height must be made greater.

The sinking of a slope is similar to gangway driving, and the tracks and timbering are kept well up to the face.

The timbering is very similar to gangway timbering, except that squared timber is more frequently used (but it is not necessary) and the joints are cut with more care. On steep pitches, a heavy "mud sill" is let into the rib on each side, to prevent the road from slipping down the pitch.

The Sump.—When the shaft or slope is completed, among the first things necessary is a sump in which to collect the drainage of the mine. This is an opening lower in the vein, when it is a pitching one, or in the rock when it is a flat seam reached by a shaft. It should be large enough to hold any excess of water that the pumps cannot handle; and the pumping machinery should be powerful enough to handle the ordinary drainage by running not over 10 hours per day. When this is the case, in an emergency, the pumps can be run continuously, and thus handle the surplus water.

Driving the Gangway.—In bituminous coal seams, the height of the gangway is governed by the thickness of the seam, and this is also true, in a certain sense, in the anthracite regions. But in the anthracite regions they are very seldom less than 6 ft. in height. In the larger seams they are from 6 ft. 6 in. to 7 ft. 6 in. high in the clear, and from 10 to 15 ft. wide. The gauge of track varies from 24 to 48 in. The grade should rise at least 4 in. in 100 ft., and a gutter 3 ft. wide by 18 in. deep should be cut in the coal on the low side. This gutter should be a *gutter*, and not a receptacle for refuse. There is no economy in a shallow gutter, or in neglecting it because it costs a few cents a day to keep it open. Some authorities advise a rise of from 6 in. to 1 ft. in every 100 ft., but they evidently do not take into consideration that so great a rise means a loss of from 26 to 53 ft. in lift at the end of a gangway a mile long, or, in other words, in the loss of from 68,000 to 137,000 sq. ft. of the area of coal to be reached by the gangway. This applies to pitching seams. Where the seam is flat, or nearly so, the gangway must, of course, be driven on a grade that best suits the formation. Turnouts constructed on each side of the shaft or slope, of a suitable length, are a necessity, if the slope or shaft is to be kept constantly supplied with coal. These turnouts vary in length, depending on the length of the cars, and the number necessary to keep the machinery in motion between trips. They should be wide enough to allow at least 3 ft. in the clear between the bodies of the cars; 5 ft. is even better. When possible to avoid it, there should be no center props between the tracks.

Levels in Metal Mines.—The cross-section of the level depends largely on the character of the ore mined, and the desired output from the deposit. In the case of precious metal mines, producing high-grade mineral from narrow veins, the levels are driven as small as possible. Immediately adjoining the

shaft there is a plat or station the full width of the shaft. This is heavily timbered and provided with a double track, but, as a rule, the levels have but a single track, and in some cases there is but a single track at the shaft, there being a turnout or switch in the level a short distance from the shaft. In this class of mines, 5 ft. × 6½ ft. in the clear would probably be the average size of a level, it being driven as small as possible. In the case of mines producing lower grade material and handling heavy tonnages from large deposits, as, for instance, in some of the iron and copper mines, the levels are driven larger, and in some instances are double-tracked, being from 7 ft. to 8 ft. high in the clear, and from 7 ft. to 12 ft. wide inside timbers; but, even in this class of mines, in most cases single-track levels 7 ft. × 7 ft. to 8 ft. × 8 ft. in the clear are employed with turnouts or passing points at intervals, and a double or triple track at the shaft. The levels are usually driven with a slight grade away from the shaft, so that they will drain to the shaft, and the grade will be in favor of the loaded car. In some mines where electric tramming is employed, the levels are so driven that the motor makes a circuit through the mine, following the foot-wall in one direction, and returning along the hanging wall, or one of the drifts may be in the country rock. Such systems as this are employed only in large properties handling a very great tonnage.

TUNNELS.

Mining tunnels are usually of small cross-section compared with those that occur in railroad work, it being rare that their size is such that they cannot be driven in full section, and if the ground is firm the operation of placing the lining may follow behind the work of driving. They are generally lined with timber, and in case the ground is of a soft or treacherous nature, bridged square sets and forepoling are employed, with or without breast boards, as the necessity of the case demands. When the material is firm rock, the tunnel is sometimes not lined, the roof being given an arched form. The various forms of timbering employed as tunnel linings are shown in the sections on Timbering.

MINE TIMBER AND TIMBERING.

Choice of Timber.—Timber used for underground supports in mines should be long-grained and elastic, and, at the same time, should not be too heavy. Oak, beech, and similar woods are very strong, but are heavy to handle, and when set in place are treacherous, owing to the fact that they are short-grained and not elastic, so that, though strong, when they do break, they break without warning. Mine timber is placed, not with the intention of ultimately resisting the great pressure of the earth, but so that it may keep any loose pieces in place and also to give warning to the workmen, thus enabling them to escape before a fall occurs. For this reason, pine and fir are, as a rule, better for mine timbering, as they combine a fair amount of strength with considerable elasticity, and hence give warning long before they break. Very elastic timbers, such as cypress, willow, etc., are, as a rule, to be avoided, on account of the fact that they will simply bend like a bow, without offering the necessary resistance to hold the material in place for a short time.

Preservation of Timbers.—The character of the ventilation in a mine has considerable effect on the life of any timber supports. Damp stagnant air will cause mold and fungus growth, which will be followed by the destruction of the timber through decay or dry rot. All timbered openings should be well ventilated, and provision made for the speedy removal of damp hot air, such as commonly occurs around pump rooms and along steam lines.

Water is a good preservative, as it washes off the spores of the fungi as fast as they are formed, and sometimes shaft timbers are kept wet on account of the preservative action of the water.

Timber may be also preserved (1) by a solution of common salt and water; (2) by impregnating the wood with such metallic substances as sulphates of copper, iron, etc.; (3) by impregnation with the chloride of magnesium or zinc; (4) by creosoting; (5) by coal tar; (6) by carbolineum.

A solution of 1 lb. of salt in 4 or 5 gal. of water gives a cheap and easily applied preservative with which the timber should be thoroughly soaked.

Sulphate of iron is economical and effective. In the zinc process, a solution of 1 gal. of liquid chloride of zinc (Sp Gr. 1.5) mixed with 35 gal. of water is forced into the wood by pressure. Impregnation with crude creosote oil is effective, but it has the disadvantage of making the timber very inflammable. Creosote acts in a threefold manner: (1) It fills the pores and prevents saturation by water; (2) it destroys organic life; (3) the carbolic acid that it contains coagulates the albuminoids and prevents decay. Painting with liquid tar is effective, but makes the wood very inflammable. Painting with ordinary whitewash is also said to give good results. Carbolineum is said to be effective, but is quite expensive. It is applied with a brush, or by steeping in a tank; 1 gal. will cover 300 to 400 ft. of timber.

Professor Louis, of England, has shown that preservatives decrease the strength of timber from 8% to 20%, depending on the process used.

The following table gives the results of tests made by different methods of treating wood at Saint Elroy, France, and recorded in 1890:

TESTS OF PRESERVATIVES FOR MINE TIMBER.

Name of Preservative.	Relative Preservative Effect.					
	Oak.	Fir.	Pine.	Beech.	Birch.	Poplar.
Tar	27.8	263.5	87.5	105.4	26.2	150.5
Chloride of zinc	10.5	50.0	26.3	18.6	52.5	34.7
Sulphate of copper	42.1	12.0	8.0	1.8	2.5	15.5
Sulphate of iron	18.0	12.5	4.2	4.7	3.7	2.9
Creosote	1.7	2.5	4.4	0.6	3.3	1.3

The simple removing of the bark, under some circumstances, seems to be advantageous, but, in some woods, if the bark is removed, the sap wood should also be removed. In many cases, the sap wood of coniferous trees is as strong or stronger than the heart wood, and for this reason it should not be removed. Also, in the case of many coniferous trees, the bark seems to act as a protection to the timber in the underground workings. If it becomes necessary to reduce the size of the individual sticks, it is usually better to split them than to saw them, especially in the case of wood from coniferous trees, as this does not destroy the sap wood or unduly injure the grain or fibers of the stick. Generally speaking, mine timbers last longer when kept wet, and, on this account, some of the mines in Europe have introduced a system of pipes for spraying the timbers in dry portions of the mine. When timbers are alternately wet and dry, they are destroyed with amazing rapidity. Timber should be probed from time to time to ascertain its condition, as timbers may appear sound on the outside when the heart is completely destroyed by dry rot. In selecting props, the principal points to be observed are: Straightness, slowness of growth as indicated by narrow annular rings, freedom from knots, indents, resin, gum, and sap. They should also be well seasoned before use. With these precautions and proper mine ventilation, fungus growth may generally be obviated and durability insured.

Placing of Timber.—The individual sticks should never be weakened by cutting mortise and tenon joints. The pressure should be evenly distributed over a number of sticks, and not concentrated or centered at one point. Centers of revolution should be avoided. The individual sticks should be placed in the direction of the strain that they are to resist, so that they will be subject to compression along their length rather than to a transverse strain. The individual sticks should be so placed, and the joints so formed, that the pressure tends to strengthen rather than weaken the structure up to the crushing strength of the timber. In the case of large stopes, the timbering should be done according to some regular system, while, at the face of coal mines, single props or posts are usually found better, owing to the fact that their duty is only to support the loose portion of the roof for a limited time. Probably the most important point is to timber in time, before the rock becomes broken or begins to settle.

It seems generally agreed that the main weight in mines comes nearly at right angles to the bedding, and that the props should be mainly set in that direction. If the deposit is horizontal, the weight generally comes vertically; but if the deposit is inclined, the weight comes at a right angle to the inclination. Some authorities hold it as a principle that all props should be set at a rectangle against the main pressure. Others, in order to guard against possible side thrusts and a tendency of the ordinary weight to ride to the dip in inclined deposits, purposely cause a sufficient number of props to be set slightly deviating from the common axis.

Sawyer fixes a maximum and minimum slope for the props, varying with the rate of dip. He makes this maximum slope of the props one-sixth that of the dip, and the minimum slope one-third of the one-sixth.

Props are usually set with the butt end downwards, but not always. Having the butt end upwards adds a trifle to the weight on the lower end, but the larger size at the top should lessen the liability of its being split by a coupling resting on it, and also gives more surface for abrasion in hammering up against a rough roof. Both ways may therefore have advantages according to the circumstances. The butt end downwards, with air circulating, is the way Molesworth recommends for stocking.

Size of Timber.—The general tendency at all metal mines at present is toward the use of systematic frames composed of small sizes of timber, rather than toward the use of large individual sticks. The advantages are: (1) the small timber is cheaper and easier to procure; (2) it is easier to handle, and hence costs less to place in position. By making the frames according to some regular system, the individual sticks can be framed on the surface by machinery so that better joints are secured. The setting of timber can be done by less experienced help when it is all alike.

Joints in Mine Timbering.—In all mine timbering, the object is to so form the joints that no fastenings will be necessary and that the shape of the pieces will be such that the pressure from the surrounding material will keep the joints tight. The reason for this is that any metal joints usually corrode rapidly in mines, and that, when it becomes necessary to replace timbering, this can be done with greater ease if the sticks are so framed that, by relieving them temporarily of the pressure from the sides and top, they can be simply lifted out of place and new ones substituted. The use of a framing machine renders it possible to frame the joints more exactly than with hand framing. With hand-framed timbers, the joints are always cut a little free to allow for any unevenness in the surface, but, if machine-framed, they are sure to be of the same size. As timber does not shrink in the direction of its grain, it is evident that where the posts meet, if the caps shrink slightly, they will become loose in the space between the shoulders; hence, if timbers are cut green and framed to the exact size, subsequent shrinking may open some of the joints. This may be obviated by keeping the timber moist.

The method of taking timbers into a mine depends on the size and number of timbers used and on the character of the opening into the mine. In drift or tunnel mines, timbers are sent in on flat cars built especially for the purpose, or in the regular mine cars. In vertical shafts, they are usually stood on end on the floor of the cage, and lashed together and also to the supports of the cage. Where the opening is an incline, it is the common practice to load the timbers into a skip and thus lower them into the mine. Timber should, wherever possible, be framed on the surface.

Undersetting of Props.—Props at the working face should not be set at right angles to the inclined floor of the seam, but should be underset, and the greater the inclination, the greater the underset. The amount of underset should vary with the inclination of the seam, and should not be so great that the props will fall out before the roof has tightened them.

Forms of Mine Timbering and Underground Supports.—The timbering of a mine may be divided into two heads: (1) timbering the working faces; (2) timbering the roads.

The roof may be supported (*a*) by packing the waste places entirely where sufficient material is obtainable for the purpose, and timbering the faces and roads; (*b*) by partially packing the waste, by buildings or stone pillars with intervening spaces, and by timbering the face and roads; (*c*) by timbering the face and roads and supporting the roof in the waste places by wooden or stone pillars, but without any packing; (*d*) by timbering alone without any packs or walls whatever; (*e*) by supporting the main roads with brick arching, or by steel or iron supports.

The accompanying plates include all the common forms of mine timbering and underground supports.

Fig. 1 shows a **post** *a* and **breast cap** *b*. The breast cap *b* is also sometimes called *cap, head-block, headboard, lid,* or *bonnet.* Sometimes the posts are placed upon blocks of wood similar to the head-blocks or headboards, the block being called a *sole;* at other times, two or more posts may be set upon one long block of timber called a *sill.* When posts are used in inclines, they should not be set perpendicular to the foot and hanging walls, but should be underset slightly, so that any tendency of the hanging wall to settle will bring the posts nearer at right angles to the walls, and so tighten them; the amount of underset should never be more than one-sixth the pitch of the deposit. Where posts are set at an angle, they are usually placed on wedges, and, as the pressure comes on, the wedges are tightened.

Fig. 2 represents a **stull** *a*, which is used either to keep the walls of perpendicular or steeply inclined beds or veins apart, to support planking or lagging as a working platform, or as a platform upon which to pile ore or rock.

Fig. 3 represents **cockermegs**, which are simply timber frames employed in coal mines for holding the face of the coal in place while it is being undercut. They are composed of a pole *c* extending along the face and supported by short stulls or braces *a*, the whole being tightened into place by the long stulls *b*.

Fig. 4 shows a **crib, cog, chock, pillar,** or **shanty** built up of timbers and filled with waste rock. It is intended to serve as a pillar and to withstand great vertical pressure, doing away sometimes with the necessity of leaving pillars of ore.

Fig. 7 is a cribbing framed from round timbers laid skin to skin, and used in raises or ore chutes.

Gangway or Level Timbers.—Fig. 5 is a set employed in the case of an extra-wide gangway, there being a center post under the middle of the cap. This form of set may be provided with a sill when the floor of the drift or gangway is soft.

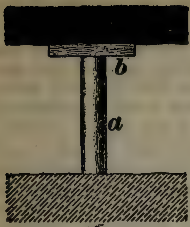
Fig. 6 shows a form of drift set surrounded by bridging and used where such bad ground is encountered as to necessitate forepoling. *A* are the posts, *B* the caps, and *C* the sill of the regular set; *D* are upright bridge pieces; *E* a horizontal bridge piece separated from the set proper by blocks *F* so as to provide spaces *H* around the regular set through which the spiles or forepoles can be driven.

Fig. 8 shows a form of drift set sometimes employed in very heavy or swelling ground. This method of framing the timbers shortens each piece and reduces the transverse strain on all the timbers.

Fig. 9 shows an ordinary drift set provided with a sollar for ventilation purposes. An additional brace *b* is placed parallel to the cap *c*, and this is covered with plank lagging *a*, so as to provide a passage above the regular drift, which may be used as a return air-course.

Fig. 10 is a simple form of drift set employed when the roof and walls are of soft material, but the floor material firm. It is composed of posts *l*, upon which is placed the cap *c*. The joggle cut into the cap to receive the heads of the post should never be less than 1 in. nor more than one-third the thickness of the cap. The cap is usually made of such a length that the posts *l* have an inclination or batter as shown in the illustration, thus giving greater strength to resist side pressure without decreasing the floor area of the drift, which may be necessary for drains, ditches, water pipes, etc. at the sides of the track. When the floor is not composed of solid material, the posts *l* may be set upon a sill that is framed to fit the legs in a manner similar to that shown for the cap. The joggle cut in the sill should never be less than 1 in. nor more than one-third the thickness of the sill. The sill is usually composed of lighter material than the cap, is flattened on one or both sides, and is sometimes used as one of the ties to receive the track.

Fig. 11 shows a **post** *l* and the cap or **collar** *c*, used where one wall is of firm material. On one end the cap is placed in a hitch. When the collar is supported in a hitch, it is sometimes said to be *needled*, the operation being called "needling." The bottom of the post *a* is also secured in a hitch, in case there is any side pressure. To keep the surrounding material in place, lagging is necessary, as shown behind the timbers in Figs. 5, 10, and 11. In the case of running ground, the lagging is usually made from sawed material and driven close together.



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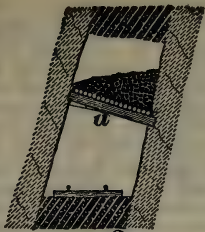

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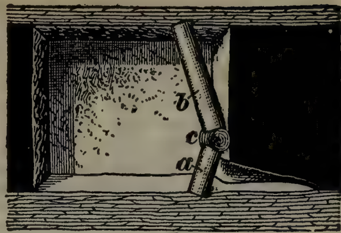

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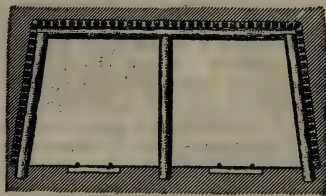
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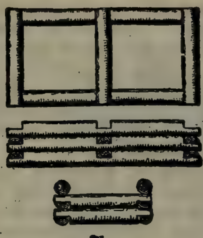
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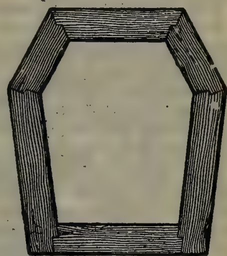
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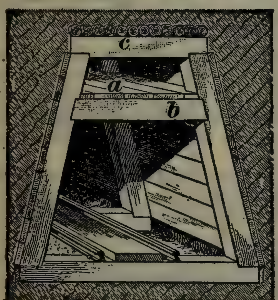

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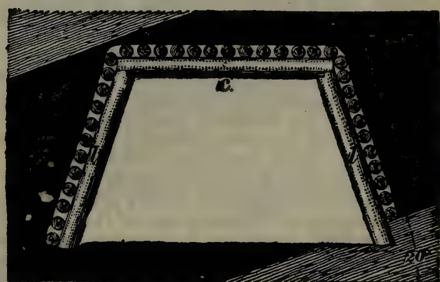

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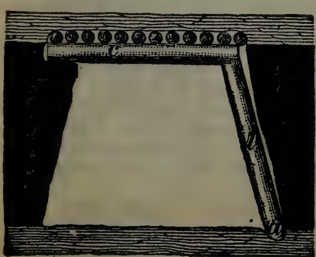

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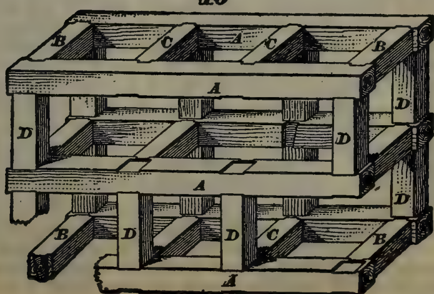

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Fig. 13 illustrates a method of **spiling or forepoling.** *a* are the posts of the regular set, *b* the caps, and *e* the top bridging. The front ends of the spiles from any given set rest on the bridging of the next advanced set, and the spiles for advancing the work are driven between the bridging and the set, as shown in the illustration. To force the spiles out into the ground, so as to provide room for the placing of the next set, *tail-pieces i* are employed; these are placed behind the back end of the spiles as they are being driven. After the spiles have been driven forward the desired amount, another set is placed, the tail-pieces knocked out, and the front end of the spiles allowed to settle against the bridging of a new set. Where the face is composed of extremely bad material, it may be necessary to hold it in place with *breast boards*, as shown at *k*, the breast boards being held in place by props *l*, which rest against the forward set. When breast boards are used, it is usually necessary to employ foot and collar braces between the sets, so as to transfer the pressure of the breast back through several sets.

Fig. 14 shows a method of placing drift sets in the case of very heavy or swelling ground. *a* are the posts, *c* the sills, *b* the caps, *d* are the *collar braces* that bear against both the caps and the posts, while *e* are *foot* or *heel braces* that bear against both the sills and the posts; *f* are *diagonal braces* that are halved together and placed as shown.

Shaft Timbering.—Fig. 12 shows square-set timbering, sometimes employed for shaft lining. *A* are the wall plates, *B* the end plates, *C* the buntons, and *D* the posts. The method of framing the different parts is plainly shown.

Fig. 15 represents **cribbing** sometimes employed for shafts. It is composed of heavy sawed material halved together at the ends, as shown. The long pieces *a* are called *wall plates*, and the short pieces *b*, *end plates*. Between the compartments a partition is built up of pieces *c* called *buntons*. The ends of the buntons are let into the wall plates an inch or so, as shown in the illustration, and should be so placed that they will break joints with the individual pieces of the wall plates, thus preventing the timbers of any single set from bulging into the shaft.

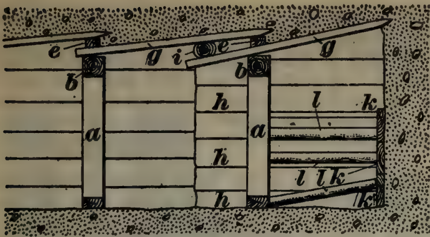
Fig. 16 shows another method of framing, sometimes employed for the end and wall plates where square-set timbering is used in shafts. The end and wall plates are halved together as shown. A beveled face is often formed at *D*. This construction necessitates the cutting of a tenon on the end of the post *F* as shown. *S* is a 2″ × 2″ strip nailed along the center of the back of the wall and end plates as a support for the lagging that is placed outside of the sets. The lagging is usually composed of 2″ or 3″ plank.

Fig. 18 shows the use of hangers between the individual square sets. The hangers are bolts provided with hooks on the ends, and are employed to support the sets as the work progresses, the posts serving to keep the sets properly spaced, while the hangers keep the sets tight against the posts. Hangers are not always left in permanently, but may be removed after a considerable section of the shaft has been completed.

Fig. 19 shows a method of applying rough square sets, made from round timber, to the sinking of a small prospecting shaft by the use of forepoling. *A* is the first set of timbers and *J* the second. The hangers are made from 2″ × 4″ timbers *F* spiked to the sets and to the supports *G*. The supports *G* from which the sets are hung are placed over sills *H*, which are situated at a convenient distance from the collar of the shaft. *D* represents the lagging of the first set that is usually spiked to the set. *K* is the forepoling that becomes the lagging between the second and third sets, and *C* the tail-pieces employed for forcing the lagging out into the ground. The hangers between the next two sets would be spiked to the other two timbers of the sets. Where the bottom of the shaft is very bad, it may be necessary to use breast boards, as illustrated in Fig. 20, in which the shaft is being put down by means of square sets and forepoling with the use of breast boards.

Square Sets.—Fig. 21 illustrates one method of framing square-set timbers from sawed material for use in stopes in mines. *A* are the posts, *B* the caps and sills, while *C* are the *sprags* or *stuttles*. The method of framing the joints is clearly shown in the illustration. Sometimes both caps and sprags are made of the same sized material and are framed alike.

Fig. 17 shows a method of framing round timbers for square sets. The dimensions *f* and *c* are usually made about 10 in., *d*, *e*, and *i*, each 2 in.; *a* depends on the diameter of the post; *b* is usually cut down to an angle of about 45°.



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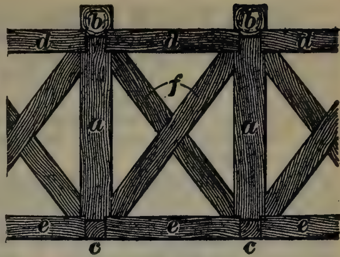

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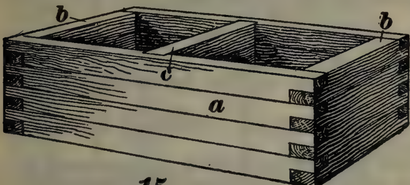

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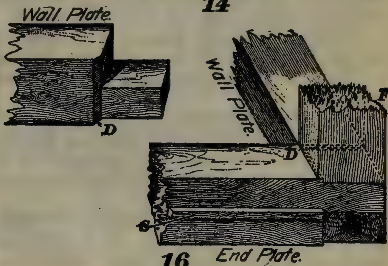

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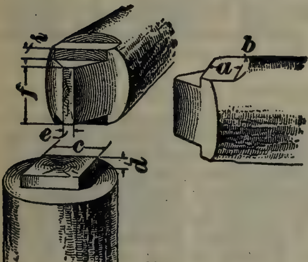

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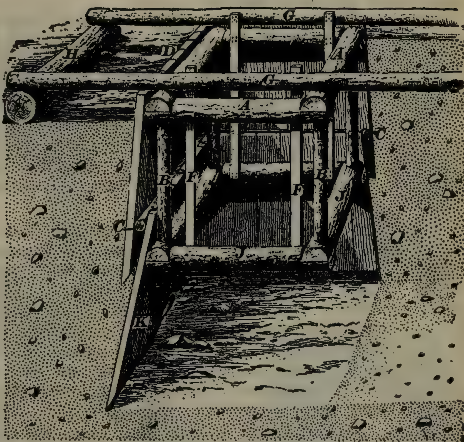

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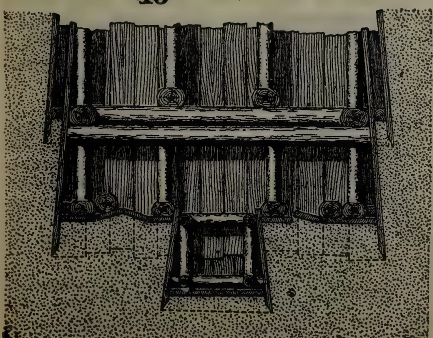

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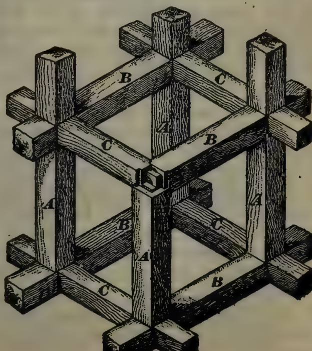

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Landings, Plats, or Stations.—Fig. 22 is one method of timbering a plat or station. The regular square-set timbering of the shaft is continued past the station and the heavy stull or reacher *a* put across at the bottom of the station. The posts *b* are bolted against the posts of the sets and the cap *c* placed on top of them. After this, the wall plates are cut out between the posts *b*, and the station opened and timbered as shown in the illustration. The height of the station is gradually reduced to that of the drift or level connecting with it.

Fig. 23 represents a method of timbering a level in a slope where the ground is so firm that only stulls are employed in the slope and at the station, the timbers all being secured in hitches or by stulls. *a* represents the stulls and *c* the timbers that are spiked to the stulls and carry the stringers for the car track. *b* represents the car track from the level that is brought across above the skip track.

Special Forms of Supports.—Fig. 24 shows a stone arch which as a stull supports the waste material in the level.

Fig. 25 shows a stone arch when one wall of the formation requires support.

Fig. 26 illustrates a passage lined by a combination of stone or brick walls with wooden caps and lagging for the roof.

Fig. 27 illustrates the lining of a drift or level supported by means of iron or steel shapes bent into the form of an arch and employed for the support of lagging.

Fig. 28 illustrates a cast-iron post or stull that has been successfully used as a support in mines. It is composed of two pieces *a* and *b*, held together by a collar *c*. By driving *c* down on the post, the two pieces can be taken apart and the post moved.

Fig. 29 illustrates a masonry shaft lining supported by means of cast-iron plates *C* set in bell-shaped cavities cut in the walls of the shaft. As the masonry of a section from below is built up toward that above, the overhanging portion *D* is cut out a little at a time, and the masonry from below built up under the plate so that the lining becomes continuous.

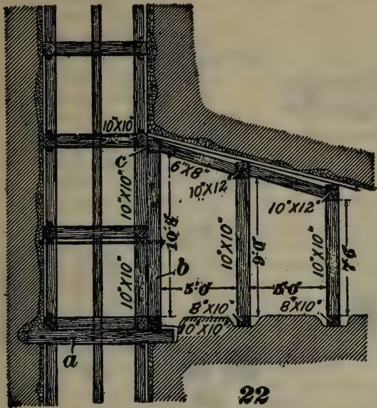
Fig. 30 illustrates masonry shaft linings, supported by artificial stone or cement foundations built in bell-shaped cavities cut in the walls of the shaft. The blocks of artificial stone are provided with inclined bearings *C*, which serve to transmit a portion of the downward thrust of the lining in the direction of the arrow.

Iron and Steel Supports.—The use of iron or steel, either for vertical or horizontal supports in mines, has not become at all general. In America, timber is as yet comparatively cheap in most mining localities, but this situation is fast changing and the timber reserves are being rapidly cut off, so that many mines now using wood must, in the comparatively near future, resort to some other form of support. Some of the disadvantages of metal supports are their greater initial cost, and on this account it is essential that all such supports should be recovered. As very little timber is recovered in American mining, this objection is one that will probably continue. The mine water is often of such a character that it will dissolve iron or steel; particularly is this the case in copper mines, and in any mines where there is much pyrites. Metal mines keep their shaft sets open but a short time compared with the pit bottoms of large coal mines, and hence the extra cost of metal construction is frequently not warranted. The districts in which metal mines are located are more likely to be disturbed than is the ground over a coal mine, and if timbering is crushed, it is much easier to repair than iron or steel. Another objection to metal supports is the fact that they cannot be as easily framed and worked as timber.

On the other hand, the life of metal is, under ordinary circumstances, much greater than that of timber, and while the inital cost may be greater, whenever the metal can be recovered it can be used over and over again, and it always has a certain value as scrap iron or steel. After a metal beam has bent, it can still be used by simply turning it upside down. Another advantage for steel is that it occupies less space than timber or masonry, and thus gives a larger effective area of roadway for the same cost of driving, or else the amount of excavation may be reduced.

Although metal has not been greatly used for props or upright supports, it has been quite extensively used, both in America and abroad, for supporting shaft bottoms and landings, and in England it has been quite successfully used for cross-bars in timbering roads, the bar being set upon wooden legs. In some of the European mines, a complete metal casing has

been used. In locations where a constantly increasing pressure comes upon the roof, an elastic bending material must be used, and in such case, soft steel is greatly to be preferred to cast iron.



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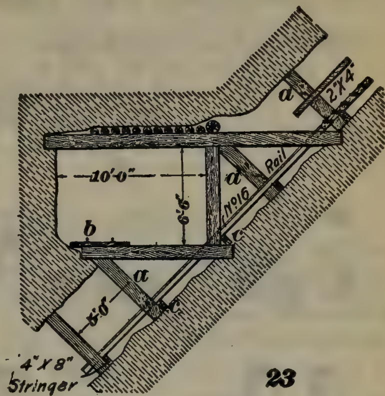

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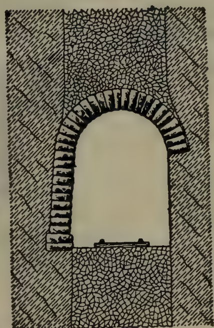

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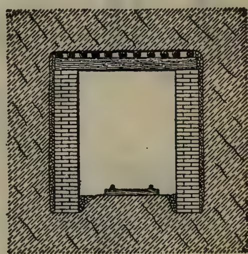

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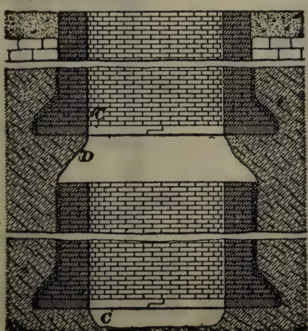

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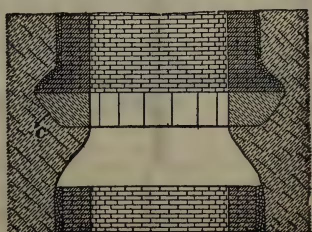

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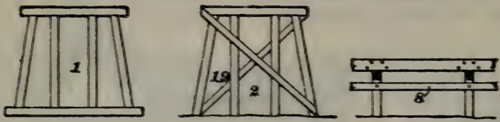
Trestles.—Figs. 31 and 33 illustrate the various timbers and methods of cutting the joints for ordinary railroad trestles. In Fig. 33 the portion (*a*) at the left illustrates the manner of framing a pile trestle, while the portion (*b*) at the right represents the manner of placing timbers and cutting the joint for the framed trestle. Fig. 31 represents bents of a frame and pile trestle



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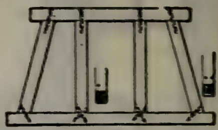

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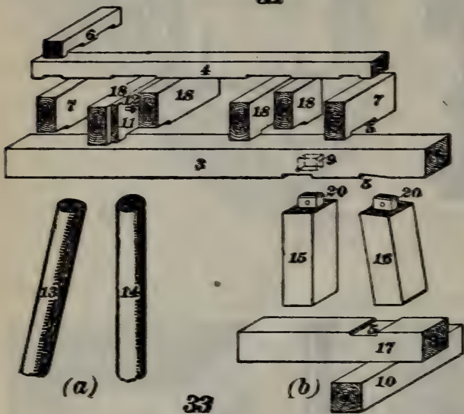

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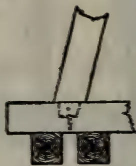

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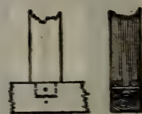

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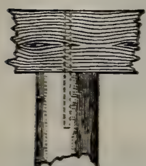

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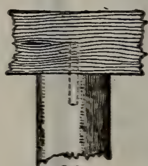

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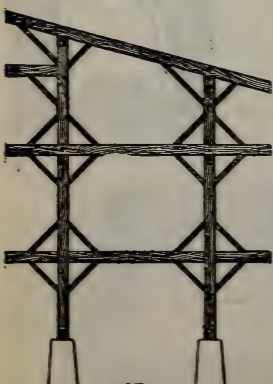

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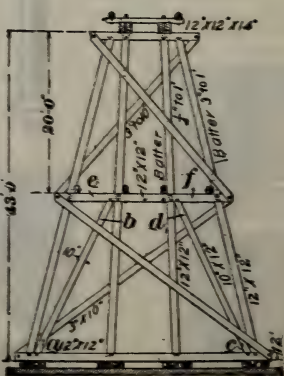

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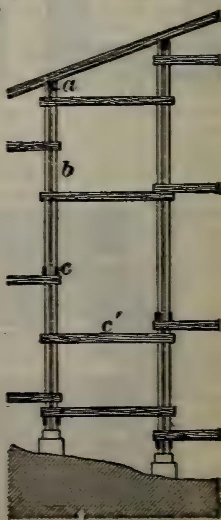

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and the side elevation of a low pile trestle. The various pieces in the figures are numbered, and the accompanying table gives the names of the parts.

Bent, Framed, *1.*
Bent, Pile, *2.*
Cap, 3.
Cross-Tie, 4.
Dapping, 5.
Gaining, see Dapping, *5.*
Guard-Rail, 6.
Jack-Stringer, 7.
Longitudinal Brace, 8.
Mortise, 9.
Mud Sill, 10.
Notching, Gaining, Dapping, *5.*
Packing Block, 11.
Packing Bolts, 12.
Piles, Batter, Inclined, Brace, *13.*
Vertical, Plumb, Upright, *14.*
Posts, Vertical, Plumb, Upright, *15.*
Batter, Inclined, *16.*
Sill, 17.
Stringer, 18.
Sway-Brace, 19.
Tenon, 20.
Waling Strip, see Longitudinal Brace, *8.*

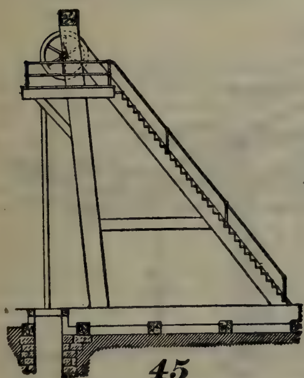
Fig. 32 illustrates a bent of a frame trestle that is fastened together entirely by means of drift bolts, no joints whatever being cut.

Figs. 34 and 35 illustrate one manner of cutting the tenons and mortises on the ends of the batter braces and posts and frame bents, and also the drain holes that are bored in the mortise to prevent the timber from rotting. Usually the sills are notched or boxed to receive the ends of the timbers, in addition to having mortises formed in them. Figs. 36 and 37 show such joints for receiving the batter brace and post.

Fig. 38 illustrates the manner in which a tenon is sometimes formed on the top of the pile to secure the cap. When the cap is secured by a tenon, the two are united by a wooden pin shown in the lower part of the figure, and known as a *treenail.*

Fig. 39 illustrates a manner in which the cap may be placed upon a pile trestle by splitting the cap into two pieces, *a* and *b* with the tenon *c* the full width of the pile between them.

Fig. 40 illustrates the manner in which the cap is sometimes secured to a



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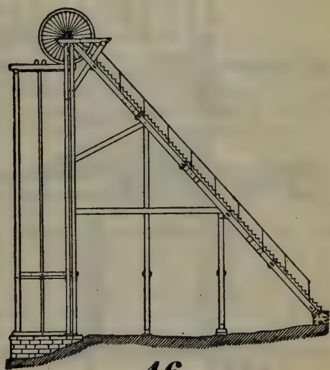

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pile by means of a drift bolt, and Fig. 41 shows the manner in which the same thing may be accomplished with the use of a dowel.

Figs. 42 and 44 show two methods of longitudinal bracing between the bents of the trestles for inclined planes, such as are used at breakers or concentrating mills.

Fig. 43 is an elevation of a high trestle, showing the cross-bracing and framing of the structure.

Timber Head-Frames or Head-Gears.—Fig. 45 is the simplest form of head-gear, which consists of a vertical post to carry the weight of the sheave, etc., and a diagonal post that approximately bisects the angle between the rope from the drum and the rope hanging down the shaft, thus taking the resultant pull upon the axle of the sheave. There is usually some extra timbering, as shown, to support the cage guides and form a platform about the sheave for convenience in oiling.

Fig. 46 shows a modified form of the same type of frame, in which the main upright leg is vertical and in which there is also another vertical

member on the opposite side of the shaft. The inclined leg is also braced and connected to the main vertical member.

Fig. 47 is a head-frame for an inclined shaft where the ore pocket is in the structure carrying the sheaves. Such head-frames are sometimes enclosed

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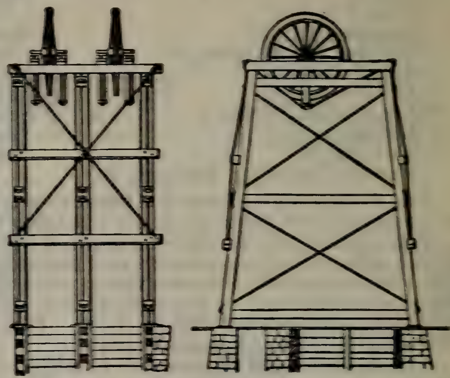

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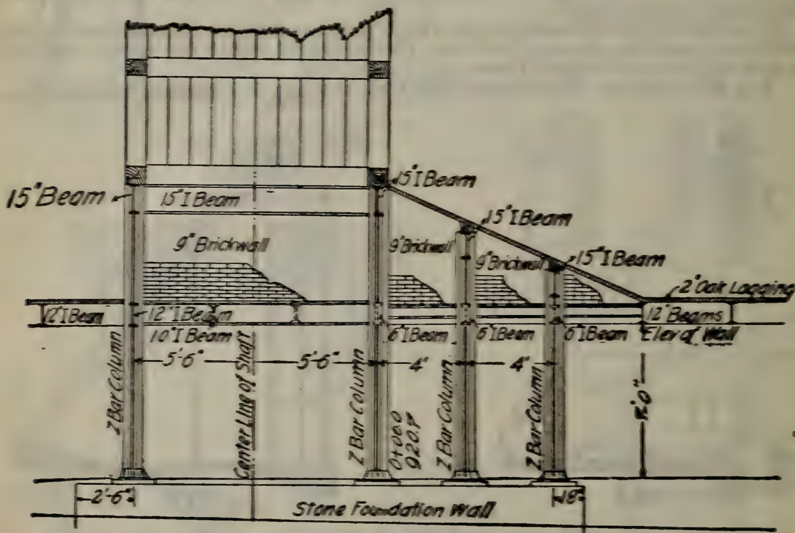

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in their upper portions in a building so as to protect the men during winter.

Fig. 48 is a form of framing quite common in the anthracite coal fields of Pennsylvania, in which the timbers are further braced by tie-rods, as shown.

Steel Shaft Bottoms.—Fig. 49 is a shaft bottom fitted with steel supports, the posts being Z-bar columns and the caps being replaced by I beams, which, in the station proper, are supported on stone or brick walls. This metal construction is employed throughout all the portion of the bottom landing and passages where the cars are handled after they are brought from the workings or before they are returned to the workings.

Undersetting of Props.—The following table, from Sawyer's "Accidents in Mines," gives the maximum and minimum angles at which props should be set for varying inclinations. This table can be taken as a general guide, but it does not take account of the length of prop nor the varying amounts of movement of the top rock under different conditions.

UNDERSETTING OF PROPS.

Rate of Inclination of Seam. Degrees.	Angle or Underset of Props.	
	Minimum Degrees.	Maximum Degrees.
6	0	1
12	0	2
18	1	3
24	1	4
30	2	5
36	2	6
42	2	7
48	3	8
54 and upwards	3	9

METHODS OF WORKING.

No definite rules can be given for the selection of a method of mining that will cover all the conditions that may exist at any given mine. Each mine is a distinct and separate proposition, and each superintendent must judge how he will adapt the general principles here given to the local conditions at his own mine. Every system of mining aims to extract the maximum amount of the deposit in the best marketable shape and at a minimum cost and danger.

OPEN WORK.

Open work applies to the working of all deposits that have no overburden, or to those in which the overburden or overlying material is stripped from the portion of the deposit to be removed by hand, steam shovels, scrapers, etc. It includes particularly all quarries and placer workings, and can be applied to many mineral and coal deposits.

The *advantages* of this system are that no timber is required; unprofitable underground workings do not have to be kept open and in repair; when required, a simple hoisting plant is used; there is less danger to the workmen from falls of roof and from blasting; there is practically no danger from fire; artificial lights are not required; mining can be done more economically, as larger faces are open, larger blasts can be used, and the amount of work accomplished per miner is greater, and better superintendence can be had; the health of the men is usually much better when working in the open; the deposits can be more easily extracted and the ore more easily and more perfectly selected, and, under proper conditions, the output can be increased almost indefinitely.

The *disadvantages* of open work are: A large amount of overburden often has to be removed and a place for sorting this waste material provided; the workmen are exposed to the weather; the expense of open work increases rapidly with depth of covering.

Open work may be divided into two general classes: *First*, where the whole or a greater part of the deposit is of value and has to be removed, as in quarries and in ordinary mines; *second*, where the valuable portion is but a small part of the whole, as in placers or fragmental deposits carrying gold, platinum, etc.

Deposits of the first class may be worked as follows: (*a*) The deposit is stripped, if necessary, and the material is removed by hoisting with derricks or a cableway, or by drawing out in cars with the use of underground passages. This class includes practically all quarries for building or ornamental stone, slate quarries, and most of the open-pit and steam-shovel iron, phosphate, and similar mines. (*b*) The deposit is stripped, and drifts or tunnels are extended through the material below the surface, either from adjacent valleys or from shafts sunk outside of the deposit. The material,

after being mined in the open pit, is thrown through openings to these drifts or tunnels, through which it is trammed to the surface or to the foot of the hoisting shaft.

Steam-shovel mines are those in which the material is, when necessary, first shaken loose by big blasts of low-grade powder, and then loaded into railroad cars with steam shovels, which lift the ore from its natural bed and deposit it in cars to be taken directly to market or to a concentrating or washing plant. Mining is thus done very cheaply, but the steam shovel, from a mechanical standpoint, is not an economical machine and the costs of repairs are high. The expense for hauling material from the steam shovel increases rapidly with adverse grades. Economy in steam-shovel mining depends on the shovel being kept constantly at work. An output of 2,000 tons per day for a steam shovel and one locomotive has been reached and even surpassed, but this cannot be taken as an average for a season's work. Under favorable conditions, there is probably no cheaper method of mining. The cost of removing 97,854 yd. of material over a seam of anthracite coal was $1 per ton of material stripped, and $0.516 per ton of coal obtained. The average depth of the stripping was 75 ft. and about two-thirds of the material removed was rock. The cost of stripping a bank 15 to 18 ft. high in Western Pennsylvania was $0.30 per cu. yd. of stripping.

By **milling system**, the deposit is stripped, shafts are sunk outside of the boundaries, and drifts are extended through the ore some distance from the surface. From these drifts, raises are put up to serve as chutes, after which the material is simply blasted loose and worked into these raises, through which it passes to the underground passages, and is trammed to the shafts and hoisted to the surface. The advantages of this system over the steam-shovel methods are: It is not necessary to make any long cut through the overburden to bring the cars on the surface of the ore body. The mining force can be employed underground in extending drifts and driving new raises in bad or stormy weather. Very little handling of the material by manual labor is required, the men simply working the loosened ore into the chutes by means of bars or shovels, without having to lift any of it. Some of the soft-ore iron mines have used this system very advantageously.

Cableways in Mining.—Cableways are extensively used for stripping deposits, for transporting material after it has been quarried, and also for mining soft or loose deposits, such as clays, phosphates, and gravels. The cost of removing the overburden varies greatly with the nature of the ground, and depends largely on the distance to which it is necessary to carry the waste material before dumping. Frequently, a cableway can be installed spanning both the place of mining and the dumping ground. In other cases, one end of the cableway is fixed and attached to a washing or gold-saving plant, while the other end revolves about this fixed point in a circle until all of the material within this circumference has been excavated; the entire plant is then moved to another location. The advantages of cableways over steam shovels or dredges are that the load may be delivered at a considerable distance from the point of excavation, while the entire apparatus rests on banks entirely clear of the excavation.

Cableways have been constructed with single spans up to 1,650 ft., handling 25-ton loads, and delivering an average daily capacity (10 hours) of 617 yd. of rock Mr. Spencer Miller places the following limitations on the practical applications of cableways: Span (single), 2,000 ft.; load, 25 tons; speed of travel, 1,800 ft. per minute; speed of hoist, 900 ft. per minute. The average practice, however, is about as follows: Span, 600 to 1,200 ft.; loads, 3 to 7 tons, speed of travel, 500 to 1,000 ft. per minute; speed of hoist, 150 to 300 ft. per minute.

Placer or fragmental deposits may be worked by means of a stream of water from a pipe or nozzle directed against the bank (hydraulic mining), or the material may be excavated by hand or by mechanical means, such as dredges, steam shovels, etc.

Hydraulic Placer Mines.—The material is broken down by water flowing over the bank, as flume waterfalls, or along the ground so as to ground-sluice the material. The material is frequently just loosened by means of picks or shovels, the current being depended on to carry it away. This is commonly called *ground sluicing*. Another method of excavating the material is to direct a stream of water against the bank from a pipe or nozzle. This is true hydraulicking. After the material has been loosened by the water, it is allowed to flow through sluices and over undercurrents or gold-saving tables so as to recover the valuable portions.

Placer Mines Worked by Mechanical Means.—Where water is scarce, the material may be excavated by steam shovels or other excavators, such as grab, or scooping, buckets, operated by cableways. The material is then washed by a limited supply of water that is frequently used over and over, or it may be passed over a dry washer or concentrator. Both the steam shovel and the cable excavator have proved very efficient means for working certain classes of deposits.

Dredge Mining.—Where the gold-bearing material lies below the water level, or where water can be introduced so as to float a boat, a dredge may be employed.

For gold dredging, a dredge should fulfil the following conditions: (1) Speed and readiness in moving and taking up different positions; (2) an adaptability for cleaning up rock, and for digging to a maximum depth; (3) feasibility of working and of the banking or disposing of the tailings; (4) cheapness in working, as most of the dredging propositions are of low grade.

Three types of dredges have been used: the hydraulic suction dredge, the shovel dredge, and the continuous-bucket ladder dredge. The first of these is well adapted for digging very small gravel and sand, but is not suited for boulders or even large stones without a great loss of efficiency. The continuous-bucket dredge has proved the most successful under ordinary circumstances, as it is controlled by lines and not by spiles or spuds, and hence can be shifted more rapidly and made to conform to irregularities in the bed rock more readily than the dipper type. Also, the continuous-bucket dredge furnishes a constant supply of material to the apparatus used for recovering the gold.

A continuous-bucket dredge can operate to a depth of 60 ft. According to Mr. R. H. Postlethwaite, of San Francisco, Cal., a decided advocate of continuous-bucket dredges, the cost of working a shovel dredge runs from 7 cents per cubic yard upwards; but he claims that the bucket dredge can be worked at a cost of from 3 to 5 cents per cubic yard, including a charge of $100 per week for depreciation. The cost of running a small gold dredger should not average over $200 per week—that is allowing $125 for wages, $50 for fuel, and $25 for repairs, etc. If the dredger handles 10,000 cu. yd. per week, that would be at a cost of 2 cents per cubic yard. If the material averaged 6 cents per cubic yard, there should be an approximate profit of $400 per week on an investment of from $25,000 to $40,000. 18 cu. ft. of gravel in place will weigh 2,000 lb.; a cubic yard will weigh 1½ short tons.

CLOSED WORK.

Under this general heading it is customary to divide the methods of mining into *coal-mining methods* and *metal-mining methods*. This classification is not entirely logical, for identical methods are applied to flat bedded deposits of coal, iron ore, clay, salt, etc., and identical or very similar methods to highly inclined coal seams and mineral veins. A more logical classification is one based on the position, character, and thickness of the deposit, but the older classification has become so firmly established that it is not advisable to give it up entirely in a pocketbook.

Bedded Deposits.—The typical and most extensive bedded mineral deposits are of coal and iron ore, and of these the former is by far the more extensively mined. A description of the several methods of mining coal beds will therefore comprise not only all of the essential points in the mining of other bedded deposits, but will include a number of points not usually considered in mining such deposits. The chief of these is the presence of explosive gas in such quantities as to influence the choice of a method of mining. From the descriptions of the methods of coal mining here given it will therefore be a comparatively simple matter for the miner of clay, iron ore, etc. to adapt a method.

COAL MINING.

General Considerations.—The elementary causes affecting the extraction of coal are (1) weight of overlying strata or depth of the deposit; (2) strength and character of roof; (3) character of floor; (4) texture of bedded material; (5) inclination and thickness of bed; (6) presence of gas in the seam or in adjoining strata.

Roof Pressure.—Of these causes, the roof pressure is the most important, and a number of the other causes are directly affected by it. The weight of the overlying cover will give a maximum roof pressure, but this may be so variously modified that the determination of the actual pressure is practically impossible, and estimates of this pressure must be based largely on practical experience; hence, rules for its calculation are of comparatively little value. One very essential point, however, must be borne in mind, i. e., that the direction of pressure is perpendicular to the bedding plane.

Strength and Character of Roof.—The strength of roof refers to the power of being self-supporting over smaller or larger areas. A strong roof permits larger openings, but increases the load on the pillars, thereby necessitating larger pillars. A weak roof requires smaller openings, and permits smaller pillars when the floor is good. A strong roof may yield and settle gradually, giving good conditions for longwall work, or it may be hard and brittle, and difficult to manage.

The **character of floor** influences largely the size of pillars. A soft bottom requires large pillars and narrow openings, especially when the roof is strong.

Texture of Coal and Inclination and Thickness of Seam.—Soft, friable coal requires large pillars, while a hard, compact coal requires only small pillars. The inclination and thickness of the deposit increase the size of pillars required, and also influence the haulage, drainage, timbering, method of working, arrangement of breasts, etc.

The **presence of gas** in the seam or in the enclosing strata affects the system of working, as ample air passages must be provided, and provision must frequently be made for ventilating separately the different sections of the mine. Where the gas pressure is strong, and outbursts are of frequent occurrence, narrow openings are necessitated that render the workings safe until the gas has escaped.

SYSTEMS OF WORKING COAL.

There are two general systems of working coal seams: (1) *room-and-pillar*, and (2) *longwall*. There are, however, a great number of modifications of each, and it is often difficult to exactly classify a given method under either of these two systems.

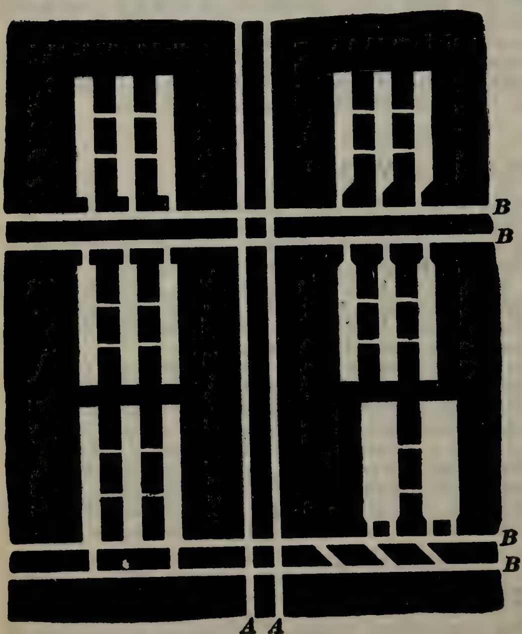


FIG. 1.

The **room-and-pillar system**, also known as the *pillar-and-chamber* or *bord-and-pillar*, and which may include the *pillar-and-stall*, system, is the oldest of the systems, and the one very generally used in the mines of the United States. By this system, coal is first mined from a number of comparatively small places called *rooms, chambers, stalls, bords*, etc., which are driven either square from or at an angle to the haulageway. These openings may be wide or narrow, and may be either a roadway, incline, or chute, according to existing conditions. The pillars that are left between the openings in the original workings support the roof, and are usually subsequently removed. All forms of room-and-pillar workings become impracticable when the thickness of the pillars necessary to support the roof pressure much exceeds double the width of the breast openings.

The pillar-and-stall system is similar to the room-and-pillar system, but in the former the stalls are opened off from the entry their full width, while in the latter the rooms or chambers are turned narrow, and widened inside to their regular width. Fig. 1 shows a typical room-and-pillar method for working an approximately horizontal seam of coal of moderate thickness (4 to 10 ft.), and with a fairly good roof and bottom. Main headings *A* are usually driven perpendicular to the strike, unless this direction is changed by the cleat in the coal, as explained later. Cross-headings, or entries *B*, *B*, are turned off at regular intervals, and at an angle of 90° to these main headings, the distance between any two pairs of cross-entries being determined, in flat seams, by twice the length to which a room can be driven, which in turn is determined by the character of the roof, floor, and seam. The rooms are turned to the right and left of each pair of butt headings, and driven until they meet, or one-half the distance between two pairs of entries. After the rooms are driven up, the pillars between the rooms are drawn, and later the room stumps along these entries, and the entry pillars themselves, are drawn, unless it should be necessary to keep some of these cross-entries open for purposes of ventilation. A large chain pillar is left to protect the main headings.

When cross-entries have been extended a considerable distance, roads are often driven between them parallel to the main heading *A*. The object of these subroads is to reduce to a minimum the air-courses and roadways to be maintained; or such a subroad may be necessary on account of a squeeze crossing any pair of cross-entries. The extent of the territory worked out to the right and left of each main entry is a matter for local determination.

The **room openings** are made suitable to prevailing conditions, and Fig. 1 shows several of the common methods. The width of the room and the form of the opening depend on the character of the roof and the extent to which it is necessary to leave a pillar to support the cross-heading, it being advantageous, of course, to open out the room to its full width at the earliest possible moment.

Longwall Method of Mining.—The longwall system contemplates the extraction of the entire seam or bed, and the original significance of the term "longwall" was a continuous line of breast. No portion of the seam is allowed to remain after leaving the vicinity of the shaft. The method depends on producing a uniform and gradual settlement of the roof a few yards behind the working face. Pack walls are built on each side of the roadways, and at regular intervals in the gob or waste area, and the roof settles firmly on these packs, pressing them into the bottom, or compressing them until the roof subsidence is complete. The height of the main roadway is maintained by "brushing" the roof or lifting the bottom. Longwall may be *advancing* or *retreating*. In longwall advancing, mining begins at or near the foot of the shaft and advances outwards, forming a gradually widening and increasing length of face to the boundary. The passages are made through the excavated portions of the mine, and are maintained by pack walls built either of the refuse secured in mining or sometimes from material brought in from the surface. In longwall retreating or withdrawing, entries, gangways, or headings are first driven to the boundary or to other convenient distances inbye, and the pillars between these entries are then drawn back toward the shaft; this is also called *working home*.

Fig. 2 shows a plan of combined longwall advancing and retreating. In the upper arrangement, or Scotch longwall, the face is semicircular and the roads are turned off at angles of 45°. This plan is suitable for seams up to 3 ft. thick with a weak top, and which pitch less than 20°, and situated at almost any depth. It is the one from which most of the longwall practice in the central coal basins of the United States is taken. In the lower portion, which shows one method of longwall retreating, narrow parallel headings are driven in pairs to the boundary, being from 200 to 300 ft. apart. Such a combination of longwall advancing and retreating insures an unvarying supply of coal, for while one side continually leaves the shaft, the other approaches it.

Longwall is specially adapted to flat seams or those having a regular and moderate pitch, and which are free from faults; to hard rather than to soft coal; and to the use of undercutting machines. It is also easy of ventilation and economical in timber, explosives, and track.

In all longwall work, the weight of the roof is made to act upon the coal face, which is undercut, according to the ability of the miner and the conditions of the seam, from $2\frac{1}{2}$ to 3 ft. deep. This weighing action of the roof

performs the work of the powder and breaks the coal in a few hours or less, after the sprags have been removed. The time required to break the coal will be greater or less, according to conditions. The success of the entire system, as will be readily seen, depends on a uniformly regular advance of the line of the face or breast, and a uniform system of setting and drawing timber at the face; also, uniformity in the pack walls along the roads, and in the amount of gob packing. This system does not permit of long idle spells induced by strikes or other causes. The coal does not break well, either, when some of the men are out a portion of the time, and their places lie idle. The life of the whole system consists in maintaining what miners call a

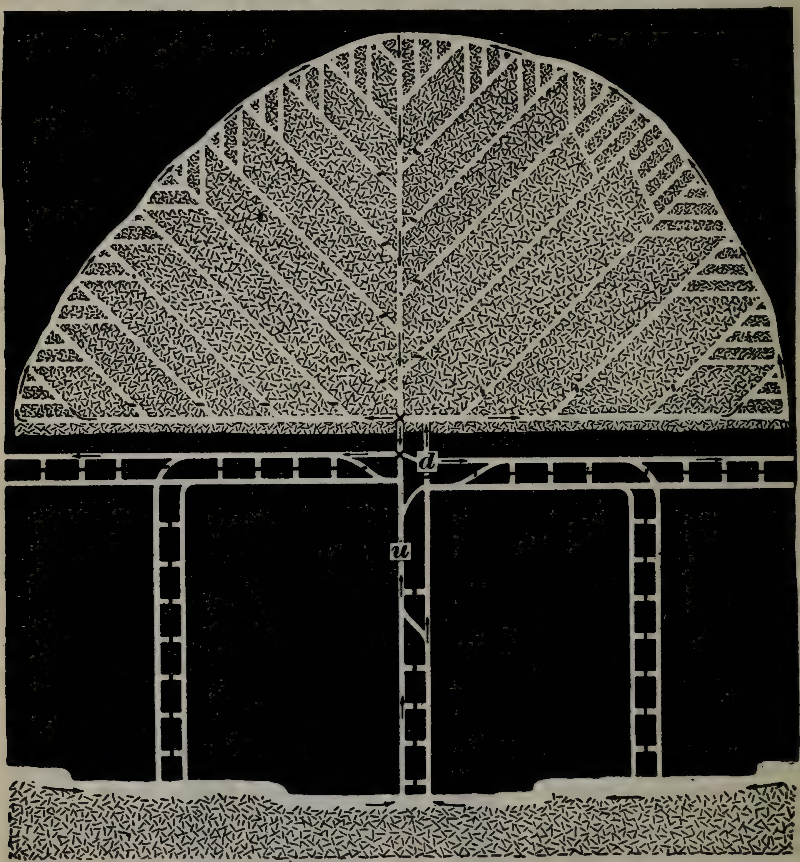


FIG. 2.

traveling weight upon the coal face, which can only be accomplished satisfactorily by uniformity in every part of the work.

Longwall advancing is better suited to thin seams than to thick ones, to flat rather than pitching, and to good roofs and hard floors.

Longwall retreating is better adapted to thicker beds; to those liable to gob fires; to seams of hard coal having a considerable pitch; to pockety, or irregular seams; and to a soft and treacherous top. The air-course is also less broken along the face, and better haulage installations can be made. Its chief disadvantage is the large amount of dead work necessitated before returns are received. With this system there is no expense in keeping up the haulage road so far as creep or falling roof is concerned, as the roads are all in solid coal, nor is there any trouble from gob fires or water; and little

detriment to the working face is caused by the mine having to stand idle for a time. If the seam is high enough for the mules or horses, no rock whatever will need to be taken down. The coal seam will be proved before 10% of it is extracted.

The ventilation in the retreating plan is as near perfect as it is possible to get it in practice. All the airways are tight, a thing impossible to get in the advancing plan; and it is a comparatively easy matter to shut off fire or to allow a portion of the working face to remain idle.

Longwall retreating is frequently used for working quite limited sections of a mine in which the seam of coal is 16 to 20 ft. thick, and inclined not more than 10°. A series of 8 or 10 pairs of headings are turned off the butt entry and driven a distance, dependent on local conditions, where the working face is formed by driving cross-cuts from one to the other. This face is carried back on the retreating plan, allowing the roof to cave in or settle on the gob as the work approaches the butt entry. In this way, any extra weight that would crush and ruin the adjacent coal is avoided. This method is also used in lower seams in which the coal is soft, or the roof, or bottom, or both, are of such a nature as to give trouble in working the room-and-pillar system. Sometimes, instead of driving pairs of headings at considerable distances apart, a number of single headings are driven comparatively close together, and connected by cross-cuts from 10 to 20 yd. apart. When the limit of the section is reached, the working face is formed and carried back, as in the other plan. This latter method is more suitable for tender roof, or a coal in which the face and butt cleats are not prominent.

Starting Longwall.—There are two methods of starting longwall workings. In the first, the work of extraction begins at the shaft itself, the coal being taken out all around and its place filled with solid packs, leaving only space for the roadways. In the second method, a pillar of solid coal is left to support the shaft, cut only by the roadways. The longwall work is then started uniformly all around this pillar. Great care is needed in building the first pack walls around the shaft pillar, to see that they are solidly built and well rammed, in order to break the roof over the coal. The system will not work rightly, however, until the breast has been advanced some distance from the pillar, so as to secure the benefit from the weighing action of the roof upon the coal face. The mining will be more difficult in the start, and in some exceptional cases it may even be necessary to place some light shots; which, however, should be avoided, if possible.

The **panel system** divides a mine into districts or panels by driving entries and cross-entries so as to intersect one another at regular intervals of, usually, about 100 yd. Large pillars are left surrounding the workings within each panel, and any method of development may be used for each panel. This system presents the following advantages: (1) Better control of the ventilation, since the air in any panel may be temporarily increased or decreased, as required. An explosion occurring in one panel is less liable to affect the other workings. (2) Coal may be extracted, pillars drawn, and the panels closed and sealed off independently of each other. (3) Greater security is afforded against creep and squeeze. (4) Coal that disintegrates on standing can be quickly worked out.

Bearing In, or Undercutting.—In any method of mining where the coal is undermined, advantage should be taken of the roof pressure to assist in both breaking down the coal and also in bearing in. The fact is often overlooked that the roof pressure upon the face coal makes it brittle and more susceptible to the pick, and the good miner starts a shallow mining in the under clay, or lower coal, and carries it the entire width of the face. By the time he returns to the side of the breast at which he started, the roof pressure has made the coal more tender and susceptible to the pick. Such a gradual system of mining throws the pressure on the coal face gradually, and the coal breaks in larger pieces. The depth of the undercut depends on the thickness of the seam and the other conditions. Undercutting by mining machines is rapidly replacing hand work wherever these machines can be used.

Buildings, Pack Walls, and Stowing.—Pack walls should be built large enough at first and kept well up to the face, to prevent the weight coming upon the timber and also to permit the roof to settle rapidly when the timber is taken out of the face. Often the roof will not stand this second movement without breaking, and possibly closing in the entire face. The face should therefore be kept in shape, and just as soon as there is room for a prop or

chock, it should be put in immediately, and the pack walls likewise should be extended after each cut or web is loaded out.

As a general thing, the pack walls in the gob are not so wide as the road-side ones, particularly when the seam produces enough waste material to stow the "marches," "cundies," or "gobs," between these pack walls. Usually about 50% of the cubical contents of the solid seam taken out will stow the spaces between the pack walls in thick pitching seams, where the entire gob must be completely filled or nearly so. No waste material, except such as will hasten spontaneous combustion, should be taken out of the mine to the surface.

Timbering a Longwall Face.—The method of timbering the working face depends on the nature of the roof, floor, coal, etc. The action of the roof on the coal face is regulated almost entirely by timber; consequently, when the coal is of such a nature as to require little weight to make it mine easily, the roof must be timbered with rows of chocks and, if necessary, a few props.

Control of Roof Pressure.—The working face of a longwall working should advance up grade, but this face cannot always be kept parallel with the strike. When the angle at the line of face, made with the line of strike, is less than 90°, the greater pressure of the covering rocks is thrown on the gob, and, when this angle is more than 90°, the greater pressure comes on the coal. The angle made by the working face with the line of pitch varies inversely as the vertical angle of pitch, or for a high pitch this angle is small and for a low pitch it is large. Where longwall is worked in adjacent sections, care must be taken to prevent the advancing of one section throwing a crushing weight on any of the others, and thus producing a crush or an uncontrollable cave. Where the rocks are pitching, and a greater portion of the cracks that cut them run in lines parallel to the strike, neither stone nor timber can efficiently support the roof, which frequently breaks off close to the working face.

The ends of all stone packs nearest the face of the coal should be in line, and the ends of these pack walls should form a line parallel to the face of the coal. Timbers set at equal distances and in line along a longwall face are much more efficient in supporting the roof than irregularly set timbers. Fig. 3 shows the proper way of locating the pack walls and the face timber.

FIG. 3.

Number of Entries.—The entries in a mine may be driven *single*, *double*, *triple*, etc.

The **single-entry** system is only advisable under certain conditions and for short distances, since the ventilation must be maintained along the face of the rooms, and there is but one haulageway, which may easily be closed by a fall or creep. Rooms are turned off one or both sides of the entry.

The **double-entry** system is most commonly used. Two parallel entries are driven, separated by an entry pillar whose thickness varies with the depth of the seam, and connected at intervals of about 20 yd. by cross-cuts or breakthroughs to maintain ventilation.

The **triple-entry** system is used particularly in very gaseous seams requiring separate return airways; or, at times, in mines where the large output requires ample haulage roads. It is usually applied to the main entries only, but sometimes, also, to the cross-entries. In gaseous mines, the middle entry is usually made the haulage road and intake airway, and the outside entries the return air-courses for either side of the mine, respectively.

A still larger number of entries even has been suggested for deep workings where it is difficult to keep open broad passages, but these have not been generally adopted or tried experimentally to any great extent.

Direction of the Face.—The typical room-and-pillar plan, Fig. 1, shows the main headings and the rooms driven parallel to the direction of the dip, and the cross-headings parallel to the strike, but in most coal seams there are vertical cleavages, called *cleats*, which cross the coal in two directions about at right angles to each other. *Face cleats*, as they are called, are the more pronounced, while the *end* or *butt cleats* are the shorter, less pronounced joints. The direction of the face with respect to the cleats is of prime importance as greatly facilitating or retarding the mining of the coal.

Fig. 4 shows the different positions that the face may occupy with respect to the direction of the cleats. The angle of the breast depends on the hardness of the coal and freedom of the cleats, and each method has its peculiar

adaptation to the varying conditions of a coal seam. When the face cleats are working free and the coal is very *soft*, it may be necessary to drive "end on." The end-on method is best adapted to a very heavy roof pressure, while for a light roof pressure the short-horn method assists in breaking the coal. If the "face" cleats are free and the coal breaks readily along them, and it is reasonably *hard*, the long-horn method is adopted, for when the coal is undercut it needs more support than it gets from the cleats, and its weight must be thrown somewhat upon the end cleats. "Face on" is adopted when the face cleats are not as free or numerous as the butt cleats. Unless the coal at the face receives sufficient support, the undercutting or bearing in cannot be thoroughly done, or else the amount of spragging and the risk to the miner are increased. When the end cleats are less pronounced and numerous, and the roof pressure great, the coal will probably break better by carrying wide breasts upon the ends of the coal, and it is then an advantage to drive double rooms with large pillars between them. In pitching seams, the pillar should have very long sides perpendicular to the strike, if the principal cleats in the coal are parallel to the strike, or nearly so.

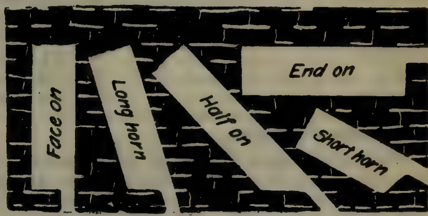


FIG. 4.

The short-horn method is adapted to heavy roof pressure and wide room pillars, as the face cleats are here quite pronounced, and the pillars between the rooms thereby weakened to a large extent; hence, wide pillars are more often employed when working on the ends of the coal. When the face cleats are less pronounced, and the end cleats are working freely, a good breast of coal is carried on the face, and, unless other conditions require it, a great width of room pillars is not needed. If this can be done consistently, and good lump coal secured at the same time, the room should cross the pitch as little as possible, as a side pressure upon the pillars having very long sides running diagonally across the pitch is destructive.

PILLARS.

Size of Pillars.—It is impossible to give exact rules or formulas for determining the proper size of pillars. Each case in practice requires special consideration, and in laying out the pillars in a virgin field it is well to find out what the current practice is in similar fields. In general, the thicker the seam and the greater its depth from the surface, the greater should be the thickness of the pillar. Some coal deteriorates rapidly when subject to weight and to the disintegrating effect of the atmosphere, and pillars of such coal must be larger than when composed of a hard, compact coal. Permanent pillars, or those that are to remain for a considerable length of time, must be larger than those that are to be promptly removed. Pillars about the bottom of a shaft, or along main haulage roads, should be left large enough to provide for increasing developments, for when landings are enlarged or when haulage systems are introduced, the original pillars frequently have to be reduced in size by taking a skip off of them or by taking out chambers for engines and pumps.

Shaft Pillars.—Various formulas have been given to determine the size of shaft pillars, and the results given by these several formulas are very diverse.

Merivale.— $S = \sqrt{\frac{D}{50}} \times 22$, where S equals the length of the side of the pillar in yards, and D equals depth of shaft in fathoms.

Andre.—Up to 150 yd. depth, have the pillar 35 yd. square, and for greater depths increase 5 yd. on each side for every 25 yd. of increased depth.

Dron.—Draw lines enclosing all surface buildings that it is necessary to erect about the head of the shaft, and make the shaft pillar so that solid coal will be left outside these lines all around for a distance equal to one-third the depth of the shaft.

Wardle.—Shaft pillars should not be less than 40 yd. square down to a depth of 60 fathoms, and should increase 10 yd. on a side for every 20 fathoms increase in depth.

Hughes.—Leave 1 yd. in width of pillar for every yard in depth of shaft.

Pamely.—Allow a pillar 40 yd. square for any depth up to 100 yd.; for greater depths, increase the pillar 5 yd. for every 20 yd. in depth.

Calculating the size of pillar from each of these authorities, we find the following variations:

Authority.	For Shaft 300 Ft. Deep.	For Shaft 600 Ft. Deep.
Merivale	22 yd. square.	31 yd. square.
Andre	35 yd. square.	45 yd. square.
Wardle	40 yd. square.	60 yd. square.
Pamely	40 yd. square.	65 yd. square.
Dron	$33\frac{1}{3}$ yd. square.*	$66\frac{2}{3}$ yd. square.*
Hughes	100 yd. diameter.	200 yd. diameter.

*Outside of buildings.

None of these formulas takes account of the thickness of the seam, and the following formula, which takes account of this very important element, was suggested by Mr. R. J. Foster, in "Mines and Minerals":

$$\text{Radius of pillar} = 3\sqrt{D \times t},$$

in which D = depth of shaft; t = thickness of seam.

Pitching seams require smaller pillars on the low side than on the rising side of the shaft.

Room Pillars.—The relative width of pillar and breast is dependent on the weight of cover, as compared with the character of the roof and floor. and the crushing strength of the coal. These relative widths are determined largely by practice. Speaking generally, the narrower the rooms or chambers, the higher the cost in yardage, the greater the production of slack and nut coal, the greater the consumption of powder, track iron, ties, etc., and the greater the cost of dead work.

For bituminous coal of medium hardness and good roof and floor, a rule often used is to make the thickness of room pillars equal to 1% of the depth of cover for each foot of thickness of the seam, according to the expression $W_p = \frac{t}{100} \times D$, in which W_p = pillar width; t = thickness of seam; D = depth of cover, and then make the width of breast or opening equal to the depth of cover divided by the width of pillar thus found, according to the expression $W_o = \frac{D}{W_p}$, where W_o = width of room.

Frail coal and coal that disintegrates readily when exposed to the air, and a soft bottom, may increase the width of pillar required as much as 50% of the amount found above; also, a hard roof may increase the same as much as 25%; while on the other hand, a frail roof or a hard coal or floor may reduce the width of pillar required 25%. The hardness of the roof affects both the width of pillar and width of opening alike, which is not the case with any of the other factors.

DUNN'S TABLES OF SIZE OF ROOM PILLARS FOR VARIOUS DEPTHS.

The following table is for first working, with the design of afterwards taking out the pillars, the width of the principal workings being 5 yd., and cross-holings 2 yd.

Depth. Feet.	Size of Pillars. Yards.	Proportion in Pillars.	Depth. Feet.	Size of Pillars. Yards.	Proportion in Pillars.
120	20 × 5	.41	1,080	26 × 14	.69
240	20 × 6	.50	1,200	26 × 16	.71
360	22 × 7	.52	1,320	28 × 18	.73
480	22 × 8	.57	1,440	28 × 20	.75
600	22 × 9	.59	1,560	30 × 21	.77
720	22 × 12	.61	1,680	30 × $22\frac{1}{2}$	.78
840	26 × 15	.63	1,800	30 × 24	.79
960	28 × 16	.66			

Extremely large pillars must often be left as a precautionary measure to protect permanent haulageways and surface buildings, or to avoid any possibility of a break in the roof that would cause an inflow of water.

Table Showing Distance From Center to Center of Breasts or Chambers Measured on the Entry or Gangway, for Different Angles.

Angle Between Chamber and Entry. Degrees.	Distance Measured on the Entry in Feet, When Width of Breast + Width of Chamber Is:											
	20	25	30	35	40	45	50	55	60	65	70	75
90	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0
85	20.0	25.1	30.1	35.1	40.2	45.2	50.1	55.2	60.2	65.3	70.3	75.3
80	20.3	25.4	30.5	35.5	40.6	45.7	50.6	55.8	60.9	66.0	71.1	76.2
75	20.7	25.9	31.1	36.2	41.4	46.6	51.2	56.9	62.1	67.3	72.5	77.7
70	21.2	26.6	31.9	37.2	42.6	47.9	53.1	58.5	63.9	69.2	74.5	79.8
65	22.0	27.6	33.1	38.6	44.1	49.6	55.1	60.7	66.2	71.7	77.2	82.8
60	23.0	28.9	34.6	40.4	46.2	52.0	57.6	63.5	69.3	75.1	80.8	86.6
55	24.4	30.5	36.6	42.7	48.8	54.9	60.9	67.1	73.3	79.4	85.5	91.6
50	25.8	32.6	39.2	45.7	52.2	58.7	65.1	71.8	78.3	84.9	91.4	97.9
45	28.2	35.4	42.4	49.5	56.6	63.6	70.6	77.8	84.9	91.9	99.0	106.1
40	31.1	38.9	46.7	54.5	62.2	70.0	77.6	85.6	93.4	101.2	109.0	116.7
35	34.9	43.6	52.3	61.0	69.7	78.5	87.0	95.9	104.6	113.4	122.1	130.8
30	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	130.0	140.0	150.0
25	47.3	59.2	71.0	82.8	94.6	106.5	118.1	127.2	142.0	153.8	165.7	177.5
20	58.5	73.1	87.7	102.4	117.0	131.6	145.9	160.8	175.5	190.1	204.7	219.3
15	77.4	96.6	115.9	135.3	154.5	173.9	192.8	212.5	231.9	251.2	270.5	289.8
10	115.2	144.0	172.8	201.6	230.4	259.2	287.3	316.7	345.6	374.4	403.1	432.0
5	229.5	286.9	344.2	401.6	459.0	516.3	572.5	631.1	688.5	745.8	803.2	860.5

In the following table, the weight thrown upon pillars at different depths by the removal of different proportions of coal is given:

Weight on Pillars in Pounds per Square Inch.

Depth of Seam. Feet.	Percentage of Coal Left in Pillars.								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
100	111	125	142	166	200	250	333	500	1,000
500	555	625	710	830	1,000	1,250	1,665	2,500	5,000
1,000	1,111	1,250	1,428	1,666	2,000	2,500	3,333	5,000	10,000
1,500	1,666	1,875	2,138	2,496	3,000	3,750	4,998	7,500	15,000
2,000	2,222	2,500	2,956	3,333	4,000	5,000	6,666		
3,000	3,333	3,750	4,384	4,999	6,000	7,500			
4,000	4,444	5,000	5,912	6,666	8,000				
5,000	5,555	6,250	7,340						
10,000	11,110	12,500							

Chain and barrier pillars vary in size even more than shaft pillars, and their widths are almost entirely determined by local considerations. In some States, the minimum width of barrier pillars is regulated by law.

Barrier Pillars.—For finding the width of barrier pillars in anthracite seams, the following formula, adopted conjointly by the chief mining engineers of the Lehigh & Wilkes-Barre Coal Co., Susquehanna Coal Co., D., L. & W. R. R. Co., Delaware & Hudson Canal Co., and the State mine inspectors of Eastern Pennsylvania, is recommended:

Formula for width of barrier pillars: (Thickness of workings × 1% of depth below drainage level) + (thickness of workings × 5).

Thus, for a seam 6 ft. thick, 400 ft. below drainage level, the barrier pillar should be (6 × 4) + (6 × 5) = 54 ft.

TABLE OF BARRIER PILLARS TO BE LEFT BETWEEN ADJOINING PROPERTIES.

DEPTH BELOW WATER LEVEL—ALL DIMENSIONS IN FEET.

FORMULA.—(Thickness of workings × 1% of depth below drainage level) + (thickness of workings × 5) = width of barrier pillar.

Thickness Mined From Seam.	0	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500
3	15	17	18	20	21	23	24	26	27	29	30	32	33	35	36	38	39	41	42	44	45	47	48	50	51	53	54	56	57	59	60
4	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80
5	25	28	30	33	35	38	40	43	45	48	50	53	55	58	60	63	65	68	70	73	75	78	80	83	85	88	90	93	95	98	100
6	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75	78	81	84	87	90	93	96	99	102	105	108	111	114	117	120
7	35	39	42	46	49	53	56	60	63	67	70	74	77	81	84	88	91	95	98	102	105	109	112	116	119	123	126	130	133	137	140
8	40	44	48	52	56	60	64	68	72	76	80	84	88	92	96	100	104	108	112	116	120	124	128	132	136	140	144	148	152	156	160
9	45	50	54	59	63	68	72	77	81	86	90	95	99	104	108	113	117	122	126	131	135	140	144	149	153	158	162	167	171	176	180
10	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200
11	55	61	66	72	77	83	88	94	99	105	110	116	121	127	132	138	143	149	154	160	165	171	176	182	187	193	198	204	209	215	220
12	60	66	72	78	84	90	96	102	108	114	120	126	132	138	144	150	156	162	168	174	180	186	192	198	204	210	216	222	228	234	240
13	65	72	78	85	91	98	104	111	117	124	130	137	143	150	156	163	169	176	182	189	195	202	208	215	221	228	234	241	247	254	260
14	70	77	84	91	98	105	112	119	126	133	140	147	154	161	168	175	182	189	196	203	210	217	224	231	238	245	252	259	266	273	280
15	75	83	90	98	105	113	120	128	135	143	150	158	165	173	180	188	195	203	210	218	225	233	240	248	255	263	270	278	285	293	300
16	80	88	96	104	112	120	128	136	144	152	160	168	176	184	192	200	208	216	224	232	240	248	256	264	272	280	288	296	304	312	320
17	85	94	102	111	119	128	136	145	153	162	170	179	187	196	204	213	221	230	238	247	255	264	272	281	289	298	306	315	323	332	340
18	90	99	108	117	126	135	144	153	162	171	180	189	198	207	216	225	234	243	252	261	270	279	288	297	306	315	324	333	342	351	360
19	95	105	114	124	133	143	152	162	171	181	190	200	209	219	228	238	247	257	266	276	285	295	304	314	323	333	342	352	361	371	380
20	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360	370	380	390	400
21	105	116	126	137	147	158	168	179	189	200	210	221	231	242	252	263	273	284	294	305	315	326	330	347	357	368	378	389	399	410	420
22	110	121	132	143	154	165	176	187	198	209	220	231	242	253	264	275	286	297	308	319	330	341	352	363	374	385	396	407	418	429	440
23	115	127	138	150	161	173	184	196	207	219	230	242	253	265	276	288	299	311	322	334	345	357	368	380	391	403	414	426	437	449	460
24	120	132	144	156	168	180	192	204	216	228	240	252	264	276	288	300	312	324	336	348	360	372	384	396	408	420	432	444	456	468	480
25	125	138	150	163	175	188	200	213	225	238	250	263	275	288	300	313	325	338	350	363	375	388	400	413	425	438	450	463	475	488	500

Each adjoining owner is to leave one-half of the pillar thickness required.

Compressive Strength of Anthracite.—Attention has recently been called by Mr. William Griffith, of Scranton, Pa., to the advisability of testing the strength of the different coals and of using this data as a basis for the proper proportioning of the pillars and for determining the probability of a squeeze. In some crude experiments, which Mr. Griffith carried on, he found that different coals from even the same locality varied greatly in their strengths. If attention were given to this matter, probably the sizes of pillars could be calculated on a much more certain basis than is possible at present, and the liability to squeeze lessened.

The table on page 290 gives the results of some preliminary and crude tests made by Mr. Griffith, which supply the only data available as to the crushing strength of anthracite coal.

Drawing pillars is about the most dangerous work the miner has to perform, but the fact of its being so is no doubt the reason why, comparatively speaking, so few serious accidents happen in it. It is not so much that the best, most skilled workmen are chosen to perform pillar drawing, as that the men, being alive to the dangers, are more on the alert and careful to protect themselves.

Sometimes, if not very often, in chamber or room-and-pillar working it is the custom to work out the rooms or chambers and leave pillars all the way from the shaft to the boundary line over large areas; in other words, the portion of the roof left standing on pillars is very extensive. Mines so worked have sometimes been spoken of as *mines on stilts.* To this mode of proceeding there are several serious objections. By leaving the pillars until the boundary has been reached, a large number of airways and roadways have to be kept open and in repair, and this number is constantly increasing until the limits of the workings have been reached. This circumstance renders the ventilation more difficult, and thereby increases risks of accident. Moreover, the length of time during which the old rooms and pillars are left open and standing increases the danger of squeeze and creep

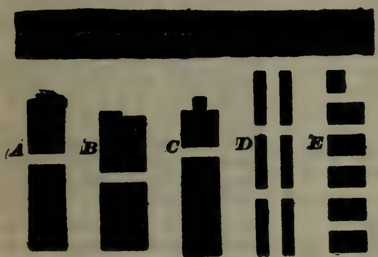


FIG. 5.

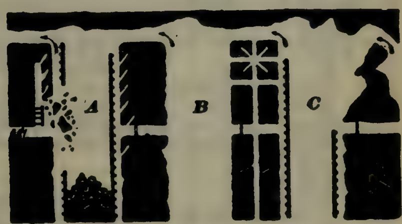


FIG. 6.

setting in, by which a large area may in a short time be overrun. Also, by this method, the pillars first formed are last removed, and hence it happens that a large number of them crack and give way under the combined action of atmospheric agencies and great pressure. Even if they resist these actions well, the quality of the coal greatly deteriorates by the long exposure.

For the above reasons, it is the best practice to carry on the two workings (working the rooms and drawing the ribs and pillars) simultaneously. By so doing, the length, mean duration of the roadways, etc. are reduced, and the pillar coal obtained in much better condition; and, in order to concentrate the workings as much as possible, the two operations should go on as closely together as practicable. With fairly thick and very soft coals, the rapid working up of the rooms and equally quick drawing of the ribs, as soon as the rooms are driven their full distance, is essential to economical working; for delay in extracting ribs and pillars in such circumstances results in their getting crushed and the coal lost or largely ground to slack, waste of props and material, disordered ventilation, and shortened life of the mine.

Methods of drawing pillars vary according to the inclinations of the seams, the nature of the roof and floor, and the character of the coal. Figs. 5 and 6 show the common methods. In Fig. 5, *A*, *B*, and *C*, the drawing begins by cross-cutting the fast ends of the pillars to obtain a retreating face. *A* shows a method for soft coal and narrowing pillars, *B* for wide

TESTS OF COMPRESSIVE STRENGTH OF SAWED PIECES OF ANTHRACITE COAL.

Number of Test.	Dimensions of Test Piece.			Weight Sustained.		Breaking Weight. Tons. Deduced.		Crushing Weight. Tons. Deduced.		Remarks.
	Length.	Width.	Height.	Breaking Tons.	Crushing Tons.	Per Sq. In.	Per Cu. In.	Per Sq. In.	Per Cu. In.	
1	$4\frac{3}{8}$	$3\frac{1}{2}$	$1\frac{3}{16}$	28 (?)	37	(?)	(?)	2.418	2.87	Checker coal from Exeter.
2	$3\frac{3}{4}$	$3\frac{3}{16}$	$2\frac{3}{8}$	17 (?)	25	(?)	(?)	2.08	4.91	Checker coal M. W. coal pile.
3	5	$4\frac{1}{4}$	$2\frac{1}{2}$	30 (?)	35	(?)	(?)	1.65	4.12	Checker coal bottom of Clear Spring colliery.
4	$6\frac{1}{4}$	6	$5\frac{1}{4}$	28 (?)	30	(?)	(?)	0.80	4.20	Clear Spring Pittston vein glassy coal.
5	8	7	6	30	75	.536	3.20	1.34	8.00	Clear Spring Marcey checker coal.
6	$4\frac{1}{2}$	$4\frac{1}{2}$	3	20	35	.99	2.97	1.72	5.16	Clear Spring Marcey checker coal.
7	$4\frac{1}{2}$	$4\frac{1}{4}$	$2\frac{1}{4}$	22	27	1.15	2.59	1.41	3.17	Clear Spring Marcey checker coal.
8	$4\frac{1}{2}$	$4\frac{1}{2}$	$1\frac{1}{2}$	38	70	1.87	2.80	3.45	5.17	Clear Spring Marcey. Very good test. Checker coal.
9	$4\frac{1}{2}$	$4\frac{1}{2}$	$1\frac{1}{2}$	32	58	1.58	2.37	2.86	4.29	Clear Spring Marcey. Knot in block. Not fair test.
10	$7\frac{1}{2}$	$7\frac{1}{4}$	$3\frac{1}{2}$	22	62	.40	1.40	1.12	3.92	Clear Spring reddish glassy coal.
11	$5\frac{1}{2}$	5	$2\frac{3}{4}$	30	(?)	1.10	3.02	(?)	(?)	Clear Spring reddish. Not fair average test.
					Average......		2.70		4.67	

pillars, the end being taken in two lifts, while C is for harder coal and shows it taken in three lifts. D and E show the pillars cut into stocks to be drawn by side or end lifts, according to the character of the coal, the inclination of the seam, thickness of the cover, and the strength or weakness of the roof and floor. Fig. 6 shows some of the methods used in robbing the pillars in steep pitching, thick beds of anthracite. To get the coal out of the pillar at the left of A, a skip is taken off the side, as shown. Successive skips are thus taken off until the whole is removed, the miner keeping the manway open to the heading below as a means of retreat. The pillar between A and B is very similarly worked. To remove that between B and C, a narrow chute or heading is driven up the middle, and cross-cuts put to the right and left a few yards from the upper end. Shots are placed in the four blocks of coal thus formed, as shown, and they are fired simultaneously by battery. This operation is repeated in each descending portion unless the pillar begins to run. A pillar from which the coal has started to run is shown to the right of C.

To secure the highest percentage of pillar coal, a method should be adopted that will prevent squeezing or crushing, if possible. All the pillars in a panel may be taken out at the same time by end lifts in such a way as to keep the face of all the lifts in line and perpendicular to the sides of the pillars, or the pillars are drawn in lifts of three or more pillars each, the centers of the face of the lifts lying in a straight line that makes an angle of about 40° with the sides

of the pillars. (See also "Flushing of Culm," which is described fully on page 314.)

Gob fires are due to the spontaneous ignition of coal, and are most likely to occur in pack walls and gobs where there is an insufficiency of air. Ample ventilation is the best preventive.

Spontaneous Combustion.—According to Prof. Able, Dr. Percy, and Prof. Lewes, the causes of the *spontaneous ignition* of coal are: *First*, and chiefly, the condensation and absorption of oxygen from the air by the coal, which of itself causes heating, and this promotes the chemical combination of the volatile hydrocarbons in the coal and some of the carbon itself with the condensed oxygen. This process may be described as self-stimulating, so that, with conditions favorable, sufficient heat may be generated to cause the ignition of portions of the coal. The favorable conditions are: A moderately high external temperature; a broken condition of the coal, affording the fresh surfaces for absorbing oxygen; a supply of air sufficient for the purpose, but not in the nature of a strong current adequate to remove the heat; a considerable percentage of volatile combustible matter or an extremely divided condition. *Second*, moisture acting on sulphur in the form of iron pyrites. The heating effect of this second cause is very small, and it acts rather by breaking the coal and presenting fresh surfaces for the absorption of oxygen.

Coal Storage.—Prof. Lewes gives the following recommendations for the storage of coal: "The coal store should be well roofed in, and have an iron floor bedded in cement; all supports passing through and in contact with the coal should be of iron or brick; if hollow iron supports are used, they should be cast solid with cement. The coal must never be loaded or stored during wet weather, and the depth of coal in the store should not exceed 8 ft., and should only be 6 ft. where possible. Under no condition must a steam or exhaust pipe or flue be allowed in or near any wall of the store, nor must the store be within 20 ft. of any boiler, furnace, or bench of retorts. No coal should be stored or shipped to distant ports until at least a month has elapsed since it was brought to the surface. Every care should be taken during loading or storing to prevent breaking or crushing of the coal, and on no account must a large accumulation of small coal be allowed. These precautions, if properly carried out, would amply suffice to entirely do away with spontaneous ignition in stored coal on land."

When the coal pile has ignited, the best way to extinguish the fire is to remove the coal, spread it out, and then use water on the burned part. The incandescent portion is invariably in the interior, and when the fire has gained any headway usually forms a crust that effectually prevents the water from acting efficiently.

MODIFICATIONS OF ROOM-AND-PILLAR METHODS.

Some modifications of the room-and-pillar plan shown in Fig. 1 can usually be applied to seams whose dip does not exceed 3°. When the pitch is greater, rooms are often turned off toward the rise only, and the cross-entries driven correspondingly closer together. When the pitch is from 5° to 10°, the cars may still be taken to the face if the rooms are driven across the pitch, thus making an oblique angle with an entry or gangway, the rooms being known as *room breasts*.

Buggy Breasts.—For inclinations between 10° and 18°, that is, after mule haulage becomes impossible and until the coal will slide in chutes, buggies are often used. Fig. 8 shows a buggy breast in plan and section. Coal is loaded into a small car or buggy *c*, which runs to the lower end of the breast and there delivers the coal upon a platform *l*, from which it is loaded into the mine car. The refuse from the seam is used in building up the track, and if there is not sufficient refuse for this, a timber trestle is used.

Another form of buggy breast is shown in Fig. 7. Here the coal is dumped directly into the mine car from the buggy. If the breast pitches less than 6°, the buggy can be pushed to the face by hand, but in rooms of a greater pitch, a windlass is permanently fastened to timbers at the bottom of the breast, while the pulleys at the face are temporarily attached to the props by chains, so that they can be advanced as the face advances. The rope used is from ½ in. to ⅝ in. in diameter, and any form of ordinary horizontal windlass can be used. With the windlass properly geared, one man can easily haul a buggy to the face of a breast in a few minutes time. The buggy runs upon 20-lb. T rails spiked with $2\frac{1}{2}'' \times \frac{3}{8}''$ spikes upon $2'' \times 4''$

hemlock studding sawed into lengths of 14 ft. This system has been thoroughly tested by the Delaware & Hudson Canal Co., Scranton, Pa., and has proved a very successful and economical one.

Chute Breasts.—Seams pitching more than 15° are usually worked by chutes, or self-acting inclines. When the pitch is between 15° and 30°, sheet iron is laid to furnish a good sliding surface for the coal. On inclinations of less than 18° to 20°, it is usually necessary to push the coal down the chute. Sheet iron is not required on pitches above 30°. It must be remembered that these pitches are only fair averages, as much depends on the character of the coal. Anthracite slides more easily than bituminous. To secure the best returns from a coal seam, the slope or shaft should be driven to the basin, and the lowest gangways or levels first driven to the property limits, and the coal then worked retreating toward the slope or shaft. Practice is, however, usually contrary to this, and the upper levels or gangways are turned off first, and working places opened out as rapidly as the gangway is driven. Fig. 9 shows a method of grouping rooms that may be

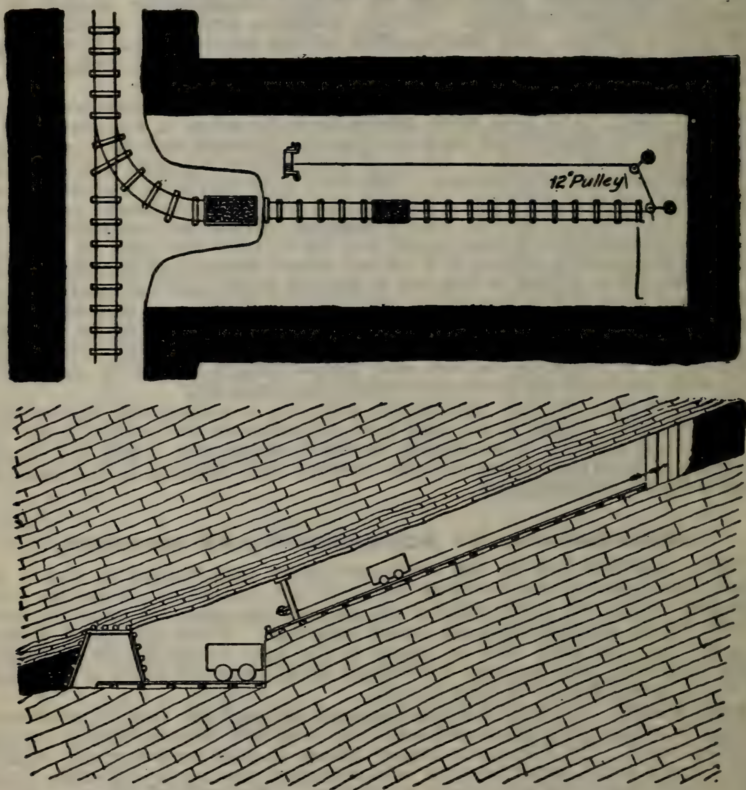


Fig. 7.

used where the pitch is from 8° to 20°, the straight heading being driven on the strike and the other headings at such angles as will give a good grade for haulage purposes.

The **pillar-and-stall** system is a modification of the room-and-pillar, to which it is similar in all respects excepting in the relative size of the pillars and breasts. The stalls are usually opened narrow and widened inside, according to conditions of roof, floor, coal, depth, etc., being from 4 to 6 yd. in the single-stall method, with the pillars about the same width. Fig. 10, *A* and *B*, shows single and double stalls. This system is adapted to weak roof and floor, or strong roof and soft bottom, to a fragile coal, or wherever ample support is required, and is particularly useful in deep seams with

great roof pressure. Double stalls are often driven from 12 to 15 yd. wide, with an intervening pillar of sometimes 30 yd.

The following are a few of the applications of the pillar-and-stall method of working as they are carried out in some of the leading coal fields of America:

Connellsville Region (*H. L. Auchmuty*).—Fig. 11 shows the common method used in the Connellsville, Pa., region. The average dip is about 5%. The face and butt headings are driven, respectively, at right angles to each other on the face and the butt of the coal. The face headings leave

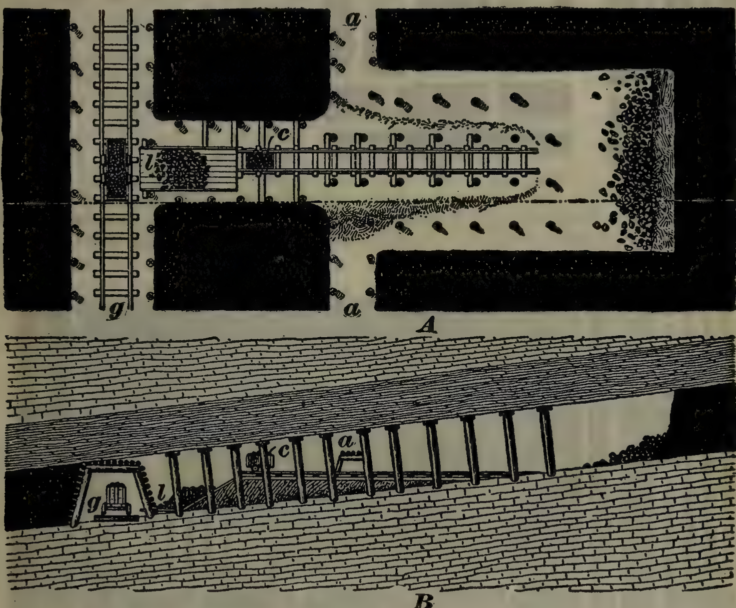


FIG. 8.

the main butts about 1,000 ft. apart, while from these face headings, and 400 ft. apart, secondary butts are driven, and again from these butts on the face of the coal the rooms or wide workings are excavated to a length of 300 ft., this having proved the most convenient length for economical working. Room pillars have a thickness of 30 to 40 ft., while the rooms are 12 ft. in width and are spaced 42 to 52 ft. between centers, depending on depth o strata over the coal. The headings are 8 ft. wide, and in all main butts and faces the distance between centers of parallel headings is 60 ft., leaving a solid rib of 52 ft. A solid rib of 60 ft. is also left on the side of each main heading. The average thickness of cover at the Leith mine, which

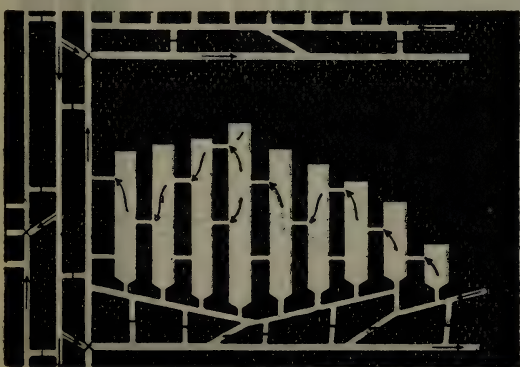


FIG. 9.

is here described and which may be considered as a type of the region, is 250 ft., the overlying measures being alternated layers of soft shale and coal for 4 ft. The bottom is an 18″ layer of hard fireclay and slate. These floor and roof materials are soft, and are easily disintegrated by air and water. At some mines, cover will reach as much as 700 ft., and the dip of 5% (as at Leith) is much heavier at some points on eastern outcrop, and will run as high as 12%, flattening off as the synclinal line of the basin is reached, until it is almost level. In some localities, the material below coal is hard limestone, requiring blasting to remove it, and at other places the roof slates are much more solid than at Leith, and not readily disintegrated. The method of drawing ribs is one of the beauties of the system, since it is harder to do successfully in a soft coal like the Connellsville coal than in hard coal. The

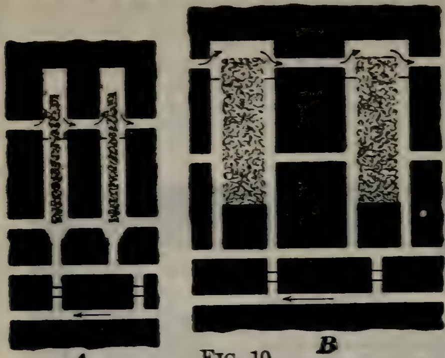


FIG. 10.

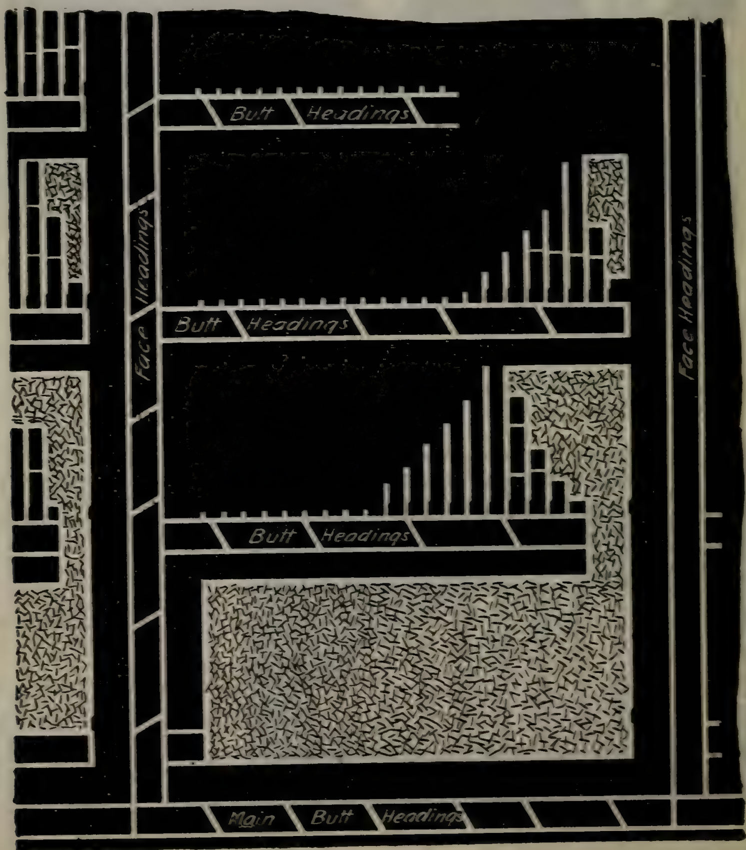


FIG. 11.

coal itself is firm. When necessary to protect the top or bottom, 4 to 6 in. of coal are left covering the soft material.

The method as given above is often applied to a whole series of butts (4 or 5) at once instead of to butt by butt, as shown in Fig. 11. In this case, work is started at the upper end of the uppermost butt and progresses, as shown in Fig. 11; but, after cutting across the butt heading from which the rooms were driven, the butt heading itself and the upper rooms from the second butt, or that just before, are likewise drawn back by continuous slices being removed from the rooms of the upper butt, and on across the next lower butt, etc., all on an angle to the butts, and so continued as the operations progress, until another butt is reached, etc., thus gradually making a longer and longer line of fracture, which is only limited by the number of butts it is desired to include at one time in the section thus mined. This works very nicely and makes long even lines of fracture, the steps of the face of the workings (in the rib drawing) being about 30 ft. ahead of one another.

Pittsburg Region (*H. L. Auchmuty*).—The coal is worked in much the same way as in the Connellsville region, except that a different system of drawing ribs is used. The coal is worked on the room-and-pillar system, with double entries, with cut-throughs between for air, and on face and butt, entries are about 9 ft. wide, and the rooms 21 ft. wide and about 250 ft. long; narrow (or neck) part of room, 21 ft. long by 9 ft. wide; room pillars, 15 to 20 ft. wide, depending on depth of strata over the coal, which is from a few feet to several hundred feet. The mining is done largely by machines of various types. Coal is hard, of course, and, in many places, the roof immediately over the coal is also quite hard. There are about 4 ft. of alternate layers of hard slate and coal above the coal seam. Rooms are mined from lower end of butt as fast as butt is driven, the ribs being drawn as mining progresses. As the coal is harder than in the Connellsville region, thickness of coal pillar between parallel entries is somewhat less.

Clearfield Region (*G. F. Duck*).—The butt and face are not strongly marked in the B or Miller seam, the one chiefly worked in this region. Where possible, these cleavages are followed in laying out the workings, but the rule is to drive to the greatest rise or dip and run headings at right angles to the right and left, regardless of anything else. The main dip or rise heading is usually driven straight, and is raised out of swamps or cut down through rolls—very common here—unless they are too pronounced, when the heading is curved around them. The same is true of room headings, except that they are more usually crooked, not being graded except over very minor disturbances.

As the B seam rarely runs over 4 ft. in thickness, and is worked as low as 2 ft. 8 in. in the haulage headings, the roof is taken down to give 5 ft. to 5 ft. 2 in. above the rail, or 5 ft. 8 in. to 5 ft. 10 in. in the clear. Where the resulting rock is taken outside, the headings are driven 10 ft. wide with 24 ft. of pillar, roof taken down in haulage heading but not in air-course. Where the rock is gobbed underground, the haulage heading is 18 to 24 ft. wide, air-course 10 ft., pillar 24 ft., and roof taken down in haulage heading only. The thinner the coal, the wider the heading. It is more economical to haul the rock to daylight. The bottom generally consists of 3 ft. to 5 ft. of hard fireclay, frequently carrying sulphur balls.

In numerous places, the sand rock is immediately over the coal, but in most cases there is from 3 to 5 ft. of slate before the sand rock is reached. Room headings are driven 280 ft. apart, haul rock to daylight, heading 10 ft. wide with 24 ft. pillar to 10 ft. air-course, in which roof is left up. A 15 ft. to 25 ft. chain pillar is left between air-course and faces of rooms from the lower heading, every fourth to eighth of which is driven through to the air-course to shorten the travel of the air. The rooms are therefore 180 to 200 ft. long, and the men push the cars to the face, an important economical item in this thin coal.

Rooms are 21 ft. wide with a 15 ft. pillar, and a 15 ft. chain pillar is left between the first room on any room heading and the main heading, and roof is not taken down in rooms. Main-heading track is usually 30-lb. iron, room heading, 12 lb., and $2'' \times \frac{1}{4}''$ strap iron set on edge is used in the rooms in low coal. Mine cars hold from 600 to 800 lb. in low seams, and 1,500 to 2,000 lb. in the so-called thick seams, i. e., 3 ft. 8 in. to 4 ft. thick.

Reynoldsville Region.—The measures are very regular, and the method employed the typical one shown in Fig. 1. The average thickness of the principal seam is $6\frac{1}{2}$ ft. and the pitch is 3° to 4°. The coal is hard and firm,

and contains no gas; the cover is light, and on top of the coal there are 3 or 4 ft. of bony coal; the bottom is fireclay. Drift openings and the double-entry system are used. Both main and cross-entries are 10 ft. wide, with a 24-ft. pillar between. The cross-entries are 600 ft. apart, and a 24 ft. chain pillar is left along the main headings. The rooms are about 24 ft. wide and open inbye, the necks being 9 ft. wide and 18 ft. long. The pillars are from 18 to 30 ft. thick.

West Virginia (*James W. Paul*).—The general plan of working the Pittsburg coal in the northern part of West Virginia is as follows. The coal measures vary from 7 to 8 ft. in thickness, and have a covering varying from 50 to 500 ft. The coal does not dip at any place over 5%. In most places the coal is practically level, or has just sufficient dip to afford drainage. The usual method of exploitation is to advance two parallel headings, 30 ft. apart, on the face of the coal. At intervals of 500 to 600 ft., cross-headings are turned to right and left, and from these headings rooms are turned off. These cross-headings are driven in pairs about 20 or 30 ft. apart. Between the main headings and

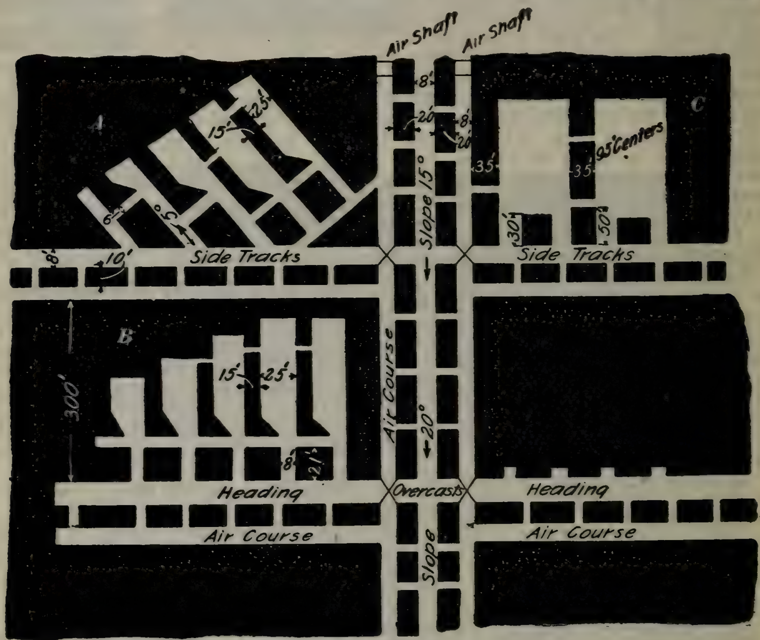


FIG. 12.

the first room is left a block of coal about 100 ft., and on the cross-headings there is often left a barrier pillar of 100 ft. after every tenth room.

The headings are driven from 8 to 12 ft. wide, and the rooms are made 24 ft. wide and 250 to 300 ft. long. A pillar is left between the rooms about 15 to 20 ft. wide. These pillars are withdrawn as soon as the panel of rooms has been finished. The rooms are driven in from the entry about 10 ft. wide for a distance of 20 ft., and then the room is increased in width on one side. The track usually follows near the rib of the room. Cross-cuts on the main and cross-headings are made every 75 to 100 ft., and in rooms about every 100 ft. for ventilation.

The double-heading system of mining and ventilation is in vogue. Overcasts are largely used, but a great many doors are used in some of the mines. Rooms are worked in both directions. This is the general practice when the grades are slight. When the coal dips over 1%, the rooms are driven in one direction only. In this case, the rooms are made longer, as much as 350 ft. It is the custom then to break about every third room into the cross-heading above (a practice ill advised). The floor of this bed of coal, being composed of shale and fireclay, often

heaves, especially when it is made wet. Some trouble is at times experienced by having the floor heave by reason of the pillars being too small for the weight they support.

The dimensions of rooms and pillars given are for a mine (with covering 300 to 500 ft. thick) having a fairly good and strong roof. Where roof, bottom, and thickness of cover change, these dimensions are altered to suit the requirements. The main-heading pillars may be reduced to 30 or 40 ft.; the rooms may be made 15 ft. wide with 12 ft. pillars, and no barrier pillars may be left on the cross-headings.

The foregoing plan is very much followed in other parts of the State; at least an attempt is made to do so, but local disturbances often require changes in the plan. This plan is followed on some parts of New River, and also in the Flat Top field.

Alabama Methods (*J. E. Strong*).—Fig. 12 shows the common methods used in working the Alabama coals. The seams now working vary from 2 to 6 ft. thick, and they pitch from 2° to 40°. Where the seams are thin, the coal is hard, and pillars of about 20 to 30 ft. are used to support the roof.

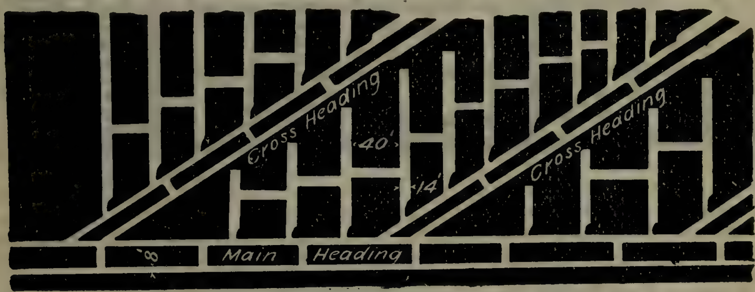


FIG. 13.

The thick seams are soft and easily broken, and much larger pillars are left. The character of bottom and top varies; fireclay bottom and slate roof are usually found with the thick seams, and hard bottom and sandstone roof with the thin seams. The general plan of laying out the mine is to drive the slope straight with the pitch of the seam; this is usually on the butts of the coal. A single-track slope is 8 ft. wide, and a double-track slope 16 ft. Cross-headings are driven or turned from the slope water level every 300 ft.; air-courses are driven parallel on either side of the slope. Where an 8 ft. slope is driven, 30 ft. of pillar are left between the slope and airway, and for a 16 ft. slope, 30 ft. of pillar. The size of pillar, however, depends largely on the character of the roof and thickness and strength of coal. On the lower side of the headings, pillars from 20 to 60 ft. are left on the entry before turning the first room. The rooms are worked across the pitch on an angle of about 5° on the rail, Fig. 12, *A*, when the coal does not pitch greater than 20°; where the pitch is greater, chutes are worked and the rooms are driven straight up the pitch (Fig. 12, *B*). In a few cases, where the pitch is not greater than 15°, double rooms are worked with two roadways in each room (Fig. 12, *C*). A rope with two pulleys is used, and each track keeps the rib side of the room, the loaded car pulling up the empty on the opposite side of the room; distance between room centers, about 42 ft. Where single rooms are worked, the room is driven narrow (8 ft. wide) for 21 ft., when connections are made with the room outside of it; the room is then widened out to about 25 ft., sloping gradually until this width is attained; pillars of from 10 to 20 ft. thick are left between the rooms, and cross-cuts for ventilation are made about every 50 ft.; every third or fourth room is driven through to the entry above; pillars are then drawn back to the entry stumps or pillars. The average cover over the coal now working is from 100 to 600 ft. Air-courses usually have an area of 30 ft., and sufficient coal is taken out to give this area, the roof and bottom being left.

George's Creek District, Md.—Fig. 13 shows the method used in the George's Creek field, Maryland. The coal shows no indication of cleats, and the butts and headings can be driven in any direction. The main heading is driven to secure a light grade for hauling toward the mouth. Cross-headings making an angle of 35° to 40° are usually driven directly to the

rise, and of the dimensions shown. Pillars are drawn as soon as the rooms are completed, being attacked on the ends and from the rooms on either side, the coal being shoveled to the mine car on a track in the room. Very wide pillars are split. No effort is made to hold up the overlying strata, and the entire bed is removed as rapidly as possible. An extraction of 85% of the bed is considered good work. A section of the seam is as follows: Roof coal, 10 in.; coal, 7 ft.; slate, $\frac{1}{2}$ in.; coal, 10 in.; slate, $\frac{1}{2}$ in.; coal, 10 in.; fireclay; slate. The top bench is bony and frequently left in place to prevent

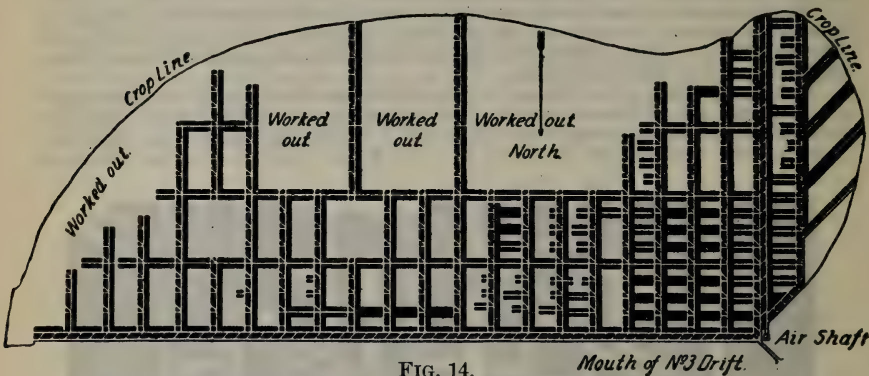


FIG. 14.

disintegration of the roof by the air. Above this coal is from 8 to 10 ft. of "rashings," consisting of alternating thin beds of coal and shale, that is very brittle, and requires considerable timber to keep it in place.—("Mines and Minerals," Vol. 19, page 422.)

Blossburg Coal Region, Pa.—Coal is generally mined from drifts, but in a few cases by slopes. Fig. 14 shows the general method adopted; the breasts are run at right angles to the slips; the breast pillars are split by a center heading and taken out as soon as the breasts are finished. The gangway pillars are taken out retreating from the crop or boundaries of the property.

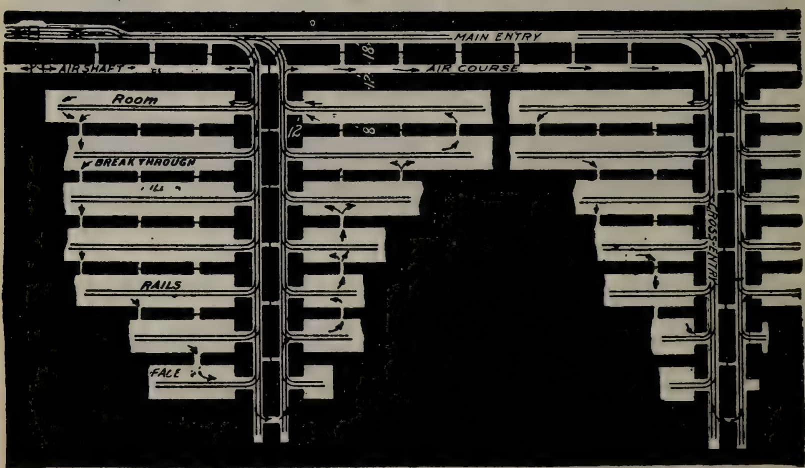


FIG. 15.

The general average of the coal seams is not over $3\frac{1}{2}$ ft., accompanied by fireclay and some iron ore. The dip of the veins is about 3%.—("Mines and Minerals," Vol. 19, page 126.)

Indiana Coal Mining.—Fig. 15 shows the double-entry room-and-pillar method as used in Indiana. The entries are generally 6 ft. high, 8 ft. broad,

the minimum height required by law being 4 ft. 6 in. The rooms are from 21 to 40 ft. in width. The mines are generally shallow. The rooms in Fig. 15 are shown as widened on both ribs, but a more usual method in this locality is to widen the room on the inbye rib, leaving one straight rib for the protection of the road in the room.—("Mines and Minerals," Vol. 20, page 202.)

Iowa Coal Mining.—The coal lies at a depth of 200 ft. below the surface, and is geologically similar to that of the Missouri and Illinois fields. It lies in lenticular basins extending northwest and southeast and outcropping in the larger river beds. The seams are practically level, non-gaseous, and generally underlaid by fireclay and overlaid by a succession of shales, sandstones, and limestones, which are generally of a yielding nature, giving a strong, good roof for mining. There are three distinct seams, the lower one, which varies from 4 to 7 ft. in thickness, being the only one worked. The coal is a hard, brittle, bituminous coal that shoots with difficulty, but is excellent for steam and domestic uses. About Centerville, the coal has a distinct cleat, but elsewhere in the State this is lacking.

The entry pillars along the main roads are 6 to 8 yd. thick, for the cross-entries 5 to 6 yd., and for the rooms 3 to 5 yd. Room pillars are drawn in when approaching a cross-cut. Both room-and-pillar and longwall methods are in use, with modifications of each. In the room-and-pillar system, the double-entry system is almost invariably used in the larger mines. Rooms are driven off each entry of each pair of cross-entries at distances of 30 to 40 ft., center to center; the rooms are 8 to 10 yd. in width, and pillars 3 to 4 yd. The rooms are narrow for a distance of 3 yd., and then widened inbye at an angle of 45° to their full width. They vary from 50 to 100 yd. in length, and the road is carried along the straight rib.

When double rooms are driven, the mouths of the rooms are 40 to 50 ft. apart, and they are driven narrow from the entry a distance of 4 or 5 yd.

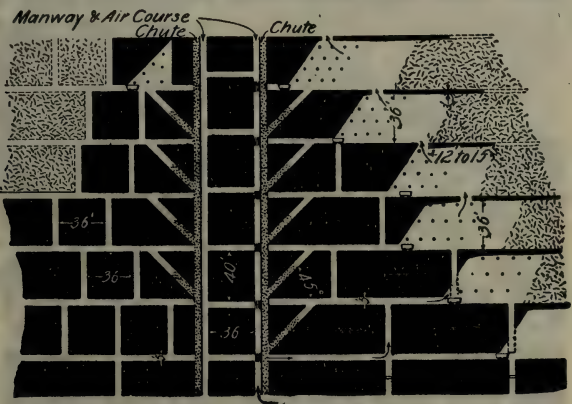


Fig. 16.

A cross-cut is then made connecting them, and a breast 16 yd. wide is driven up 50 to 60 yd. The pillar between each pair of rooms is 12 to 15 yd.

In pillar-and-stall work, the stalls are usually turned off narrow and widened inside, the pillar varying from 5 to 8 yd. The stalls are 30 to 40 yd. in length, and the pillars are drawn back. When the stalls are driven in pairs, the pillar 8 to 10 yd. in width is carried between them.

Longwall.—The main haulage road runs in each direction from the foot of the shaft, and on both sides of this diagonal roads are turned at an angle of 45°, or parallel to the main haulageway. These are spaced 10 yd. apart and driven 50 to 60 yd., when they are cut off by another diagonal road. Panel breasts are used where the conditions are such as to induce a squeeze. Rooms are turned narrow off entries and are arranged in sets of 6 to 12 rooms, with a pillar 10 to 20 yd. wide between the sets of rooms. When the rooms have progressed a short distance from the entry, they are connected by cross-cuts, and the longwall face is carried forward from this point. Packs are built and the roof allowed to settle, as in longwall. The wide pillars are taken out after the roof has settled.

Ventilation:—The system of ventilating the workings usually employed is that of conducting the air to the inside workings by means of an air-course forming the back entry of each haulage road. From this point it is carried along the face of the rooms, through the breakthroughs or cross-cuts in the room pillars, returning thence to the haulage road, which is usually made the return airway. When, however, the mine is ventilated by means of a furnace or an exhaust fan, the intake airway is usually made the haulage road, in order to avoid doors at the shaft bottom.

The **Tesla, California, method** is shown in Fig. 16. The coal seam averages 7 ft. of clear coal, and pitches 60°. This system was adopted in a portion of the mine to get coal rapidly; for, at this point, a short-grained, slate cap rock came in over the coal, making it difficult to keep props in place. The floor is a close blue slate and has a decided heaving tendency. The roof is an excellent sandstone. There is a small but troublesome amount of gas. Two double chutes are driven up the pitch at a distance of 36 ft. apart, connected every 40 ft. by cross-cuts. One side of each chute is used for a coal chute and the other for a manway and air-course. At a distance of 12 yd. apart small gangways are driven parallel with the main mine gangways. These are continued from each chute a distance of 300 ft., if the conditions warrant it. The top line is then attacked from the back end and the coal is worked on the cleavage planes; the breast, or room, therefore consists of a 12-yd. face, including the drift or gangway through which the coal is carried to the chutes; a rib of coal (2 or 3 ft.) is left between the breasts to keep the rock from falling on the breast below. Thus in each breast the

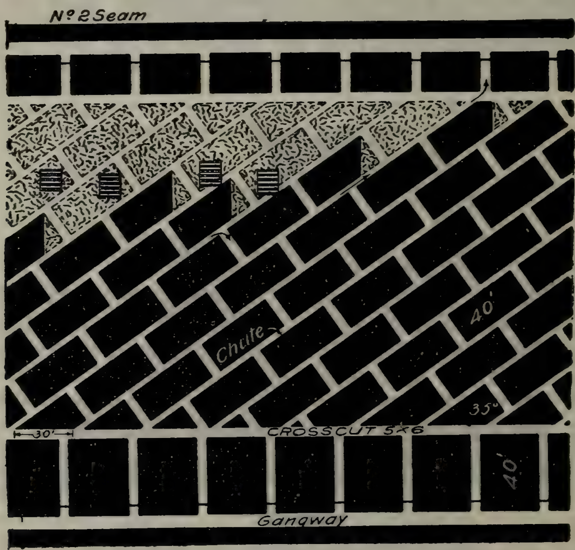


FIG. 17.

miners have a working face of about 15 or 16 yd., and as the coal is directed to the car by a light chute, moved along as the face advances, the coal is delivered into the cars at small cost, and but little loss results from the falling coal, as a minimum of handling is thus obtained. Immediately above each gangway, and starting from these main chutes, an angle chute is driven at about 45°, connecting with the breast gangway above it, and into these chutes the coal from that breast is delivered, runs into the main chute, and from it is loaded into the mine cars in the main gangway. These angle chutes serve as a means of keeping the main chute full, and at the same time giving each breast an opportunity to send out coal continuously. They also serve the purposes primarily intended, of saving the coal from breakage, by giving it a more gradual descent into the full chute. The breast gangways are driven 5 ft. wide. No timbers are needed in these gangways, as they are driven in the coal, except on the foot-wall or floor

side, which, as before stated, is a firm sandstone. It is found safest to leave a rib of coal on the top of the breast 2 or 3 ft. thick, until the working face has passed on 12 or 15 ft., when this rib is cut out and thus all the coal extracted, the roof caving behind and filling in the opening. As cross-cuts are driven every 36 ft., ventilation is kept along the working faces, and a safe and effectual means of securing all the coal in the seam is thus attained.

Fig. 17 shows another system used in No. 7 vein at the same place. The seam averages 7 ft. of coal. The roof is shelly and breaks quickly, hence the coal must be mined rapidly.

In this system the gangway chutes are driven at right angles with the strike of the seam, 40 ft. up the pitch; a cross-cut 5 ft. × 6 ft. is then driven

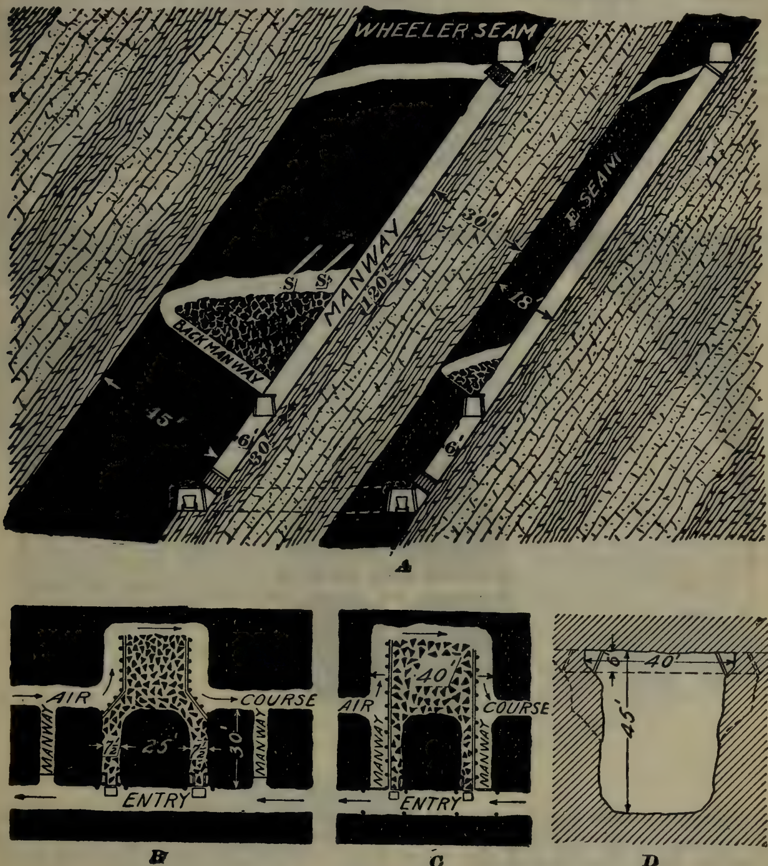


Fig. 18.

parallel with the gangway. From this cross-cut, chutes are driven at same distance apart as the gangway chutes (30 ft.), at an angle of 35°, and cross-cuts are driven every 40 ft. between chutes, for ventilation. After a panel of five or more chutes is driven up the required distance, work is commenced on the upper outside pillar and the pillars on that line are drawn and the next line is attacked, and this is continued until the panel or block is worked down to the cross-cut over the gangway. About every 80 ft. in this level it is found advantageous to build a row of cogs parallel with the strike of the seam as the pillars are drawn. This serves to save the crushing of the pillars, and prevents any accidents from falls of rock. But few timbers are required by this system.—("Mines and Minerals," Vol. 19, page 145.)

New Castle, Colorado, Method.—The following method as described by Mr. R. M. Hosea, Chief Engineer of the Colorado Fuel and Iron Co., is used at New Castle, Colo., for highly inclined bituminous seams. The coals mined are only fairly hard, contain considerable gas, and make much waste in mining. Fig. 18 shows the method used for extracting the Wheeler or thicker vein to its full width of 45 ft., and the E seam 18 ft. thick, excepting that left for pillars. Rooms and pillars are laid out under each other in the two seams whenever practicable. Entries are along the foot-wall; 30 ft. up the pitch is an air-course. Rooms and breasts are laid out as shown in *B* and *C*, Fig. 18. In the Wheeler vein, the manways go through the entry pillars to the air-course and thence along the ribs each side of the room, one manway to the main entry serving for two double rooms. A lower bench of 6 ft. is first mined the full length of the rooms, 120 ft., side manways being protected by vertical or leaning props, bordered with 3″ planks outside, and the chute or battery is then put in. At the top the rooms are connected by cross-cuts, and, occasionally, intermediate cross-cuts are required. The room is kept full of loose coal, only sufficient being drawn to keep the working floor at the proper height for the mining. When driven to the limit and with cross-cuts connected, the coal is all drawn out at the chutes, which have receptacles for rock and waste at their sides, to be picked out by the loaders. The next operation is to drive across the seam at

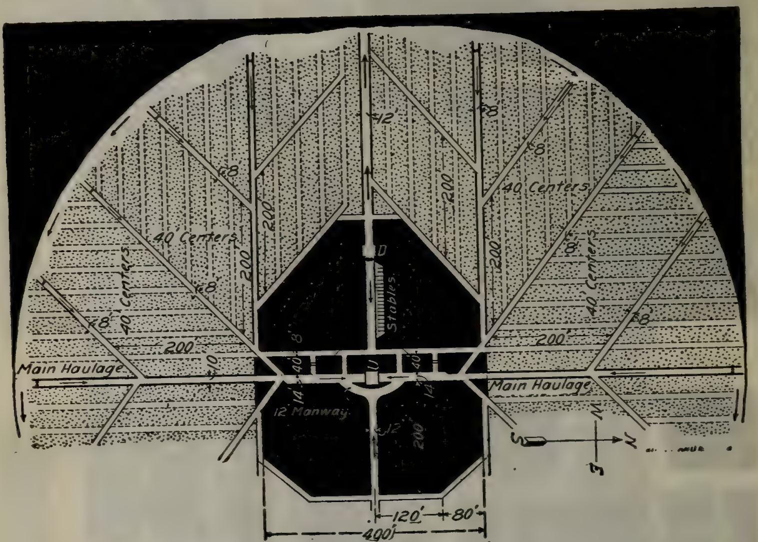


Fig. 19.

the air-course until the hanging wall is reached, manways, called *back manways*, being maintained as before. A triangular section of coal is mined off, as shown in *A*, Fig. 18, and the room filled with loose coal. The full thickness of the seam is now taken off, shots being first placed at *S S*, coal being drawn out at the bottom as required. Section *D*, Fig. 18, shows a method of robbing a pillar. In doing this, the manways are moved back into the pillar each side 10 ft. or so, by mining on the lower bench as before, and holes are drilled into the roof with long drills, which bring down as much of the overhanging part as can be reached.—("Mines and Minerals," Vol. 17, page 377.)

MODIFICATIONS OF LONGWALL METHOD.

Fig. 19 shows a good arrangement of the main and temporary haulageways in a flat seam. The chief object in any plan of longwall workings is to have the permanent roadways the arteries of the system, providing the most direct route from all sections of the mine to the shaft. The temporary

roads or working places are only maintained for a distance of 60 to 100 yd., until cut off by subroads branching at regular intervals from the main roads. In the figure, full heavy lines indicate the permanent haulageways, except only the main intake airway (12 ft. wide), running west from the downcast shaft *D*, and the main return air-course (12 ft. wide) leading from the face on the east side to the manway around the upcast *U*, which is the hoisting shaft. The full light lines indicate the diagonal subroads, driven to cut off the working places, shown by the dotted lines. The stables are located as shown in the shaft pillar, between the two shafts, where they will not contaminate the air going into the mine, but will receive air fresh from the downcast and discharge it at once into the upcast current. This position also affords ready access from either shaft in case of accident, and for the handling of feed and refuse. The pumps may be located in any convenient position at the foot of the upcast. The shaft bottoms are driven 14 ft. wide nearly through the shaft pillar, and are continued 10 ft. wide north and south through the gob. The width of all other roads and subroads is made 8 ft. The extra width of the straight road through the hoisting shaft is to provide for the future need, when the size of the workings will demand that the mine be ventilated in four sections or splits; and these two roads will then each form the return of two sections. This will be accomplished by overcasting the main road forming the shaft bottom, and carrying half the current by this means to the east face, where it is again divided. The same thing is done on the west side. The divided currents, after traversing the faces of their own respective sections, unite and return to the hoisting shaft by the main haulage road.

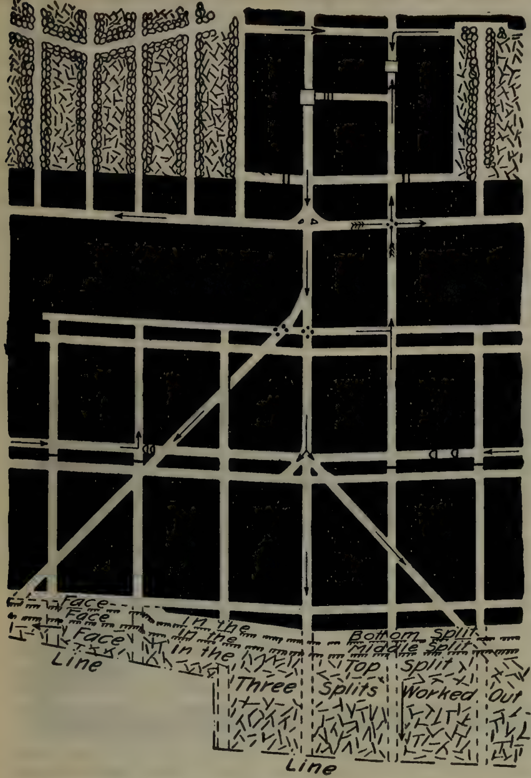


FIG. 20.

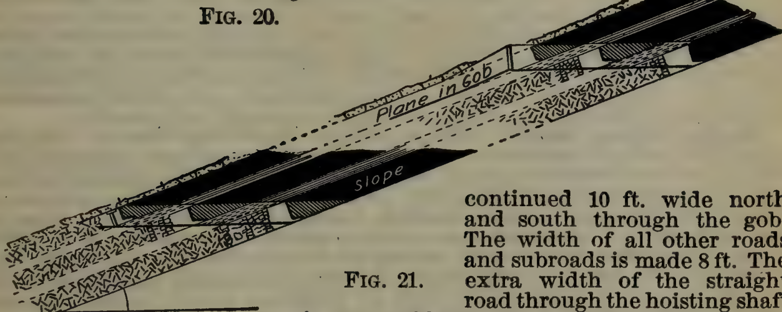


FIG. 21.

When the roof is very solid, the gob roads turn off the entries at 45°, and

may be a considerable distance apart, so that the tracks can be turned in along the working face and the mine cars loaded at the face. When the roof is tender, making it impossible to maintain sufficient room for the mine cars to pass along the face, gob roads are turned off near together, and the mine cars run to the road heads, to which points the coal is shoveled or hauled in buckets. When the working face has reached such a distance from the bottom of the shaft that it becomes impossible to work rapidly enough to avoid the destructive weighting action of the roof, the mining must be divided into panels or sections, the working face of each of which can be advanced at the proper rate.

Figs. 20 and 21 show a plan and section, respectively, of two methods largely used in Europe for working thick pitching, contiguous seams of hard, long-grained coal. From the foot of the shafts, levels are driven on the strike, and jig roads turned off these in the top seam at right angles up the pitch. The working faces are advanced in the same horizontal plane, the lower one being always ahead. The coal from the two lower seams is run through horizontal passages to the upper seam, where it is lowered to the levels below by means of jigs or gravity planes. The slates between the seams and the refuse obtained in mining are used to fill in as the faces advance. This gobbing must be done quite thoroughly, in order to prevent excessive settling of the roof and consequent crushing of the coal at the faces. Where spontaneous combustion is liable to occur, it is not advisable to use this method, but rather that shown in the lower portion of the figures. Slopes, or inclined planes, are driven down the pitch from the levels to the basin, or, if possible, to the boundary line, where the working faces are formed by driving levels to the right and left of the ends of the slopes. The working faces are here also kept in a horizontal plane with the lower one farthest up the pitch. The coal from the two upper seams is taken through tunnels or *flats* to the slopes in the lower seam, and hoisted to the shaft bottom. Here all the inclined planes or other passages are in the solid coal, and the worked-out places are left behind. A very small amount of coal is left in the mine when worked from the basin upwards, and the effects of squeezes are not felt to any great extent, as the weight of the roof is thrown on the gob. Where there is not sufficient refuse material to fill in with, it is taken into the mine from the surface, or from another adjacent mine having an extra amount of stowing material.

It is not necessary that the slopes be sunk to the boundary line, in which case the main-slope pillars should be large and left in so that the *dip workings*, as they are called, can be continued downwards when desired. In this way, the first cost of opening up is greatly reduced. The ventilation of these workings is quite simple, the intake being split at the ends of the main entries, or slopes, and the air forced along the different working faces to the right and left, and thence to the upcast by way of the main-return airways. If at all possible, it is advisable to provide an outlet near the faces of the rise workings that are advancing upwards, because the lighter gases cannot be forced down-hill with satisfaction unless an excessive velocity of the air-current be maintained. These systems are well adapted to deep or shallow mines, and to give maximum outputs for minimum development, provided the work is carried on quickly and steadily.

Overhand-Stoping Method.—Where several thick and heavily pitching seams, in which considerable firedamp is given off and the roof falls freely, are to be worked, a shaft is sometimes sunk in the adjacent strata, and at certain distances horizontal tunnels are driven to the coal seams. From these tunnels, levels or haulage roads are driven in each seam to the right and left, provided the seams are not so close together as to make it more profitable to use rock chutes or tunnels, through which the coal is run from one seam into the other. At certain intervals, depending on the length of the lifts horizontally, pairs of headings, usually called *dips*, are driven up the pitch until they intersect the levels and tunnels above. Headings are turned off these dips to the right and left, parallel to the main levels or haulage roads, and when they meet or have reached their limit horizontally they are holed, or cut through, by cross-cuts driven on the pitch. The working faces thus formed are then carried back, as shown in Fig. 22. Skips are taken off the face and the roof allowed to cave in after each operation and fill up the gob behind. The order of working is such that the top faces are worked in advance of the lower ones. The cars, which are taken to the working faces, are handled in the dips by balance carriages, or *back balances*, as they are termed in some localities. The

barney, or balance, runs on a narrow track in the middle of the track for the carriage on which the car is placed. The barney will raise the carriage with the empty car on it, and the carriage and loaded car will hoist the barney. These gravity planes are only made one-half the length of the dips, or about 150 ft., in order that greater safety may be secured and shorter ropes used. One is placed in the lower half of one of the pairs of dip headings, and another in the upper half of the other, thus necessitating that the cars be changed from one gravity plane to the other midway along the dips. This is done by taking the car off one carriage and pushing it through a break-through or cross-cut to the other. Fig. 22 shows the method of working these lifts in some parts of England and Belgium where the seams are gaseous, and some of them quite thick. The face is stepped more or less deeply, depending on the pitch, in order to protect each miner from the falling coal of his neighbor. The men reach the higher portion of the working face through timbered manways. The coal is generally run down chutes to the cars below, but in some places it is run to the end of the gangway below by means of inclined chutes, or spouts, laid on the gob. The essential feature for the successful operation of this system is the close and careful stowing of the gob between walls. In Belgium, cord wood and brush wood are very largely used for gobbing material or stowing between the regular timbers. All the coal, except very thin vertical pillars, is taken out. Where there is

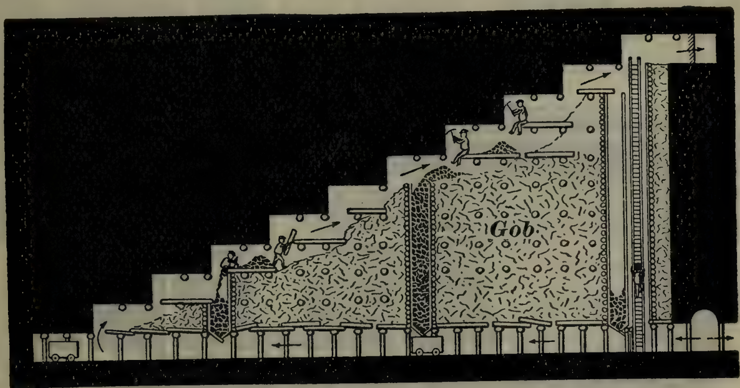


FIG. 22.

much firedamp, the miners simply nick the coal and leave it stand over night, during which time the gas either forces it off the solid or so loosens it that the miner can easily take it off with a pick. (See also Highly Inclined Mineral Deposits.)

METHODS OF MINING ANTHRACITE.

A perfectly flat seam of anthracite is seldom found in America, and even where a portion of the seam may be found lying comparatively flat, such sudden changes in dip must be expected that a system adapted to working on a pitch is almost universally used. A breast may start on a low pitch and the pitch may increase gradually until it becomes vertical, or the reverse may be the case. The cleat is usually lacking in anthracite, and the direction of driving the breasts is determined largely by the pitch and by haulage considerations.

For pitches up to 30°, the methods shown in Figs. 1, 7, 8, 9, 10, 12, and 13 are, in general, applicable, with certain changes due to local considerations. There is considerable difference in the methods of opening rooms in anthracite and bituminous mines, owing to variations in the characteristics of the coals and to the fact that anthracite will slide on chutes of less inclination than bituminous coal. Where the pitch does not exceed 4°, the rooms are turned off at right angles to the gangway. In moderately thick coal seams, pitching between 4° and 18°, the rooms are generally driven across the pitch, forming room breasts, thus securing a grade that permits the haulage of the cars to the face.

There are two methods of mining thick coal in breasts when nearly flat. (1) The breasts are opened out and driven to the limit in the lower bench of coal, and the top benches are blown down afterwards, beginning at the face and working back. (2) When the roof is good and there is no danger of its falling and closing up the workings, the upper benches may be worked in the opposite direction, beginning at the gangway and driving towards the limit of the lift, or the working of the upper bench may follow up that of the lower bench. When the seam is less than 12 ft., the top is supported by props; in thicker seams, the expense is so great for propping that but little attempt is made to support the roof. In the thicker anthracite seams (notably the Mammoth), the coal in the breasts is so worked as to make an arch of the upper benches of coal, which acts as a temporary support for the roof, the coal in the arch being extracted when the pillars are robbed.

When the inclination of anthracite seams is less than 30°, the breasts may be opened with one chute in the center, which ends in a platform projecting into the gangway, off which the coal can be readily loaded into the mine car. When this method is employed, the refuse is thrown to either side of the chute. If the pillars are to be robbed by skipping or slabbing one rib only, it is well to keep most of the refuse on one side. Sometimes, when the top is good, and the breasts are driven wide, two chutes are used, but the cost of making the second chute is considerable and is therefore not advisable unless necessitated by the method of ventilation employed.

Col. Brown's Method.—Fig. 23 shows a panel system devised by Col. D. P. Brown, of Lost Creek, Pa., which gives good results in thick seams pitching from 15° to 45°, where the top is brittle, the coal free, and the mine gaseous. Rooms or breasts are turned off the gangway in pairs, at intervals of about

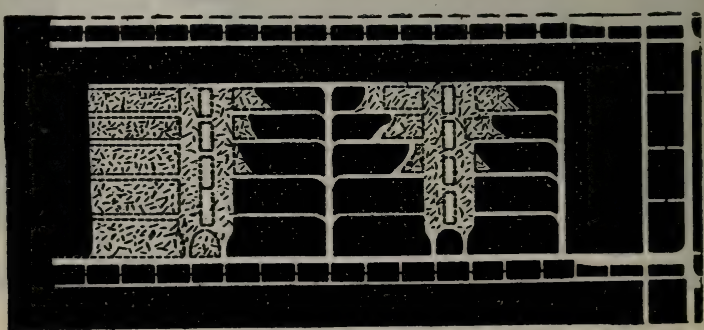


FIG. 23.

60 yd. The breasts are about 8 yd. wide, and the pillar between about 5 yd. wide, which is drawn back as soon as the breasts reach the airway near the level above. In the middle of each large pillar between the several pairs of breasts, chutes about 4 yd. wide are driven from the gangway up to the airway above. These are provided with a traveling way on one side, giving the miners free access to the workings. Small headings are driven in the bottom bench of coal, at right angles to these chutes, and about 10 or 20 yd. apart. These headings are continued on either side of the chutes until they intersect the breasts. When the chute and headings are finished, the work of getting the coal in the panel is begun by going to the end of the uppermost heading and widening it out on the rise side until the airway above is reached and a working face oblique to the heading is formed. This face is then drawn back to the chute in the middle of the panel. After the working face in the uppermost section has been drawn back some 10 or 12 yd., work in the next section below is begun, and so on down to the gangway, working the various sections in the descending order. Both sides of the pillar are worked similarly and at the same time toward the chute.

Small cars, or buggies, are used to convey the coal from the working faces along the headings to the chute, where it is run down to the gangway below and loaded into the regular mine cars. This system affords a great degree of safety to the workmen, because whenever any signs of a fall of roof or coal occur, the men can reach the heading in a very few seconds and be perfectly safe. A great deal of narrow work must be done before any great

quantity of coal can be produced. The breasts are driven in pairs and at intervals, to get a fair quantity of coal while the narrow work is being done, and they are not an essential part of the system. It is claimed that the facility and cheapness with which the coal can be mined, handled, and cleaned in the mine more than counterbalance the extra expense for the narrow work.

Battery Working.—Fig. 24 shows a method of opening a breast by two chutes *c*, *c*, when there is a great amount of refuse, or when a great amount

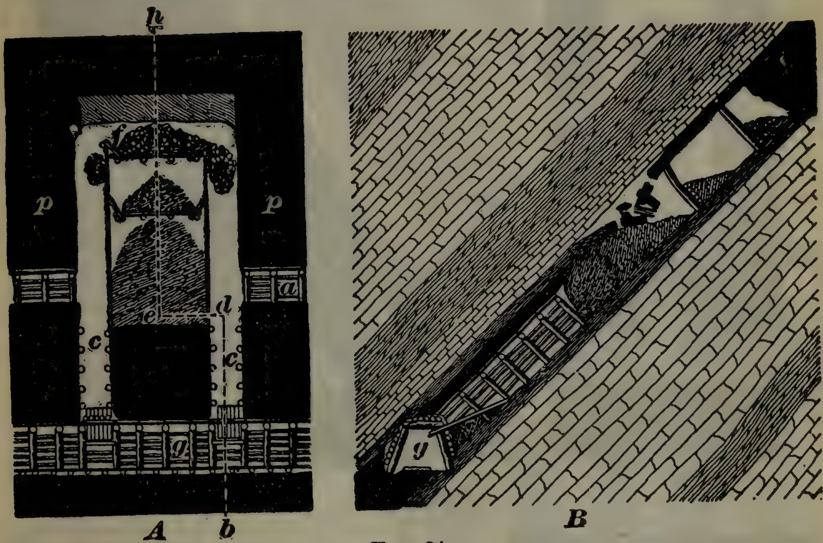


FIG. 24.

of gas is given off. The chutes are extended up along the rib to within a few feet of the working face, either by planking carried on upright posts, or by building a jugular manway, as shown in the sections (*a*) and (*b*), Fig. 25. These chutes, built of *jugulars* or inclined props and faced by 2″ plank, are made as nearly air-tight as possible, to carry the air from the heading *a* to the working face. Fig. 24 shows a breast on a pitch too steep to enable the miner to keep up to the face. In seams of less than 35°, the platform *f* shown near the face of the breast is unnecessary, and in seams thicker than 12 ft. it cannot be built; hence, this method of working is applicable (1) to beds pitching more than 35°, and (2) to thin seams.

The coal is separated from the refuse on the platform *f*, and is run down the manway chutes and loaded into the cars from a platform projecting into the gangway *g*. The refuse is thrown in the middle of the breast behind the platform. A certain amount of coal is kept on the platform to deaden the blow from the falling coal. The chutes are timbered when the character of the coal requires it. This plan can also be employed in thick seams having a heavy dip, if there is enough refuse to fill the center of the breast so that the miner can work without the platform.

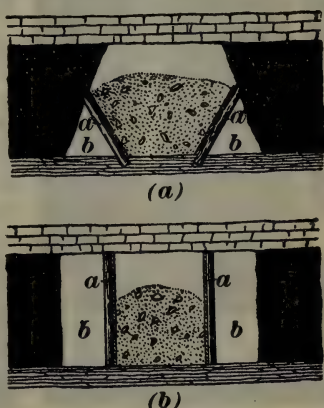


FIG. 25.

Fig. 25 (*a*) is a section through *p*, *p* when jugulars *a*, *a* are used to form the manways *b*, *b* along the sides of the breast; and (*b*) is a section through the

same line when upright posts *a*, *a* are used to support the plank in forming the manways *b*, *b*. The refuse in these cases only partially fills the gob.

In working very thick seams on heavy dips, where there is not enough refuse to fill the middle of the breast, the miner has nothing to stand on, the

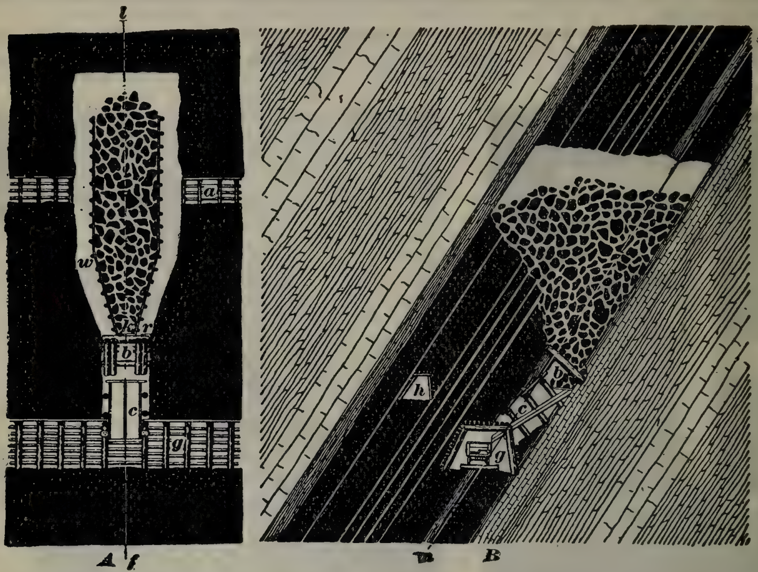
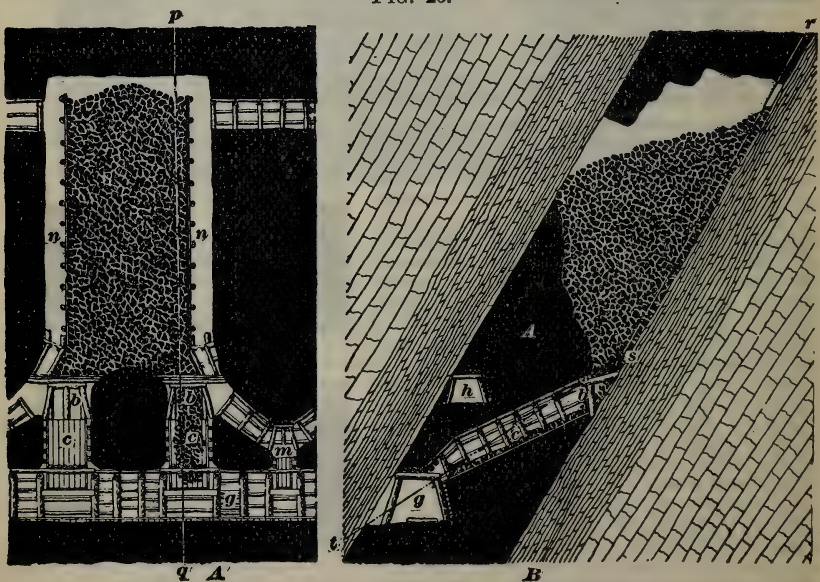


FIG. 26.



Plan along t s. FIG. 27. *Section on p q.*

platform being impracticable; therefore, it is necessary to leave the loose coal in the breast. Loose coal occupies from 50% to 90% more space than coal in the solid. This surplus is drawn out through a central chute. If the roof

is poor, the movement of the coal will not in this way cause it to fall and mix with the coal; and if the floor is soft, the jugulars, which are stepped into the floor, are not so liable to be unseated, closing the manway and blocking the ventilation. The surplus is sometimes sent down the manways, leaving the loose coal in the center of the breast undisturbed, until the limit is reached.

Single-Chute Battery.—To prevent the coal from running out through the chutes, the opening into the breast is closed by a battery constructed by laying heavy logs across the openings, as shown at *b*, Fig. 26, or else built on props, as shown at *b*, Fig. 27; a hole is left in the center, or at one side of the battery, through which the coal may be drawn. The battery closes all the openings into the breast, except the space occupied by the jugular manways, and is made air-tight, or as nearly so as possible, by a covering of plank.

Fig. 26 is a plan and section of a breast opened up by a single chute. The plan *A* is taken on the line *m n* shown on the section *B*, which section is taken on the line *f l* shown on the plan *A*. The pitch is great and the seam is so thick that the breast must be kept full of loose coal for the men to work upon, the surplus being drawn off at the battery *b* and run into the car standing on the gangway *g* through the chute *c*. A manway *w* is made along each side of the breast, for the purpose of ventilation and affording a passage for the men to reach the working face. The heading *a* is used for an air-course between breasts. The main airway *h* is driven over the gangway *g*, where it will be well protected.

By drawing the surplus coal through a central chute, the manways are not injured so much as when it is drawn off through side chutes, as the coal will move principally along the middle of the breast. When the breast is worked up to its limit, all the loose coal is run out of the breast and the drawing back of the pillars is commenced, unless for some purpose they are allowed to stand for a time.

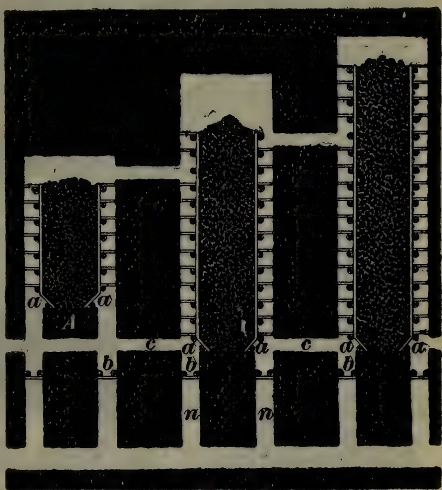


FIG. 28.

Double-Chute Battery.—Fig. 27 shows a plan and section of double-chute breasts used in very thick seams having a heavy dip. The breasts are entered by two main coal chutes *c*, *c*, each of which is provided with a battery *b*, through which the coal is drawn. A manway chute *m* is driven up through the middle of the pillar for a few yards and is then branched in both directions until each branch (slant chute) intersects the foot of a breast near the battery *b*, as shown. The jugular manways *n*, *n* are started at this point and continued up each side of the breast. The main airway *h* is driven in the solid through the stump *A* above the gangway. By driving the main gangway *g* against the roof, as shown, the pitch of the chute is lessened, and the loading chute *c* is more readily controlled.

When the main gangway is not driven against the roof, a gate is placed in the chute below the check-battery, which enables the loader to properly handle the coal. Coal in excess of the amount necessary to keep the miner up to the face may be drawn through the main battery, or sent down the manway chute, from which it is loaded through an air-tight check-battery.

The main chutes are usually 8 or 9 ft. wide, but sometimes only for the first 6 or 8 ft.; above this they are driven about 6 ft. square. The manway and *slant chutes* are also about 6 ft. square.

When the seam is not thick enough to carry the return airway *h* (Fig. 27) over the gangway, the chutes are driven up in the same manner as in Fig. 27, for a distance of about 30 ft., where they intersect the airway. The breast is opened out just above the airway, a battery being built in the airway

immediately above each chute. A manway is driven from the gangway up through the middle of the stump until it intersects the airway, and a *trap door* is placed at this point to confine the air. This manway is made about 4 ft. × 6 ft., or smaller.

Fig. 28 shows a less complicated plan than Fig. 27. The main chutes *n*, *n* are driven up to the heading *c*, from which the breast is opened out; a log battery is built at the top of each chute at the points marked *a*, *a*. The chutes are used for drawing the battery coal, and for receiving the manway coal, and are also used for traveling ways. A check-battery *b* is placed in the chute to prevent the air-current from taking a short cut from the gangway through the chute to the breast airways. This check-battery is of great assistance to the loader when the chute has a very steep pitch, as he can readily control the flow of coal through the draw-hole.

FIG. 29.

All these methods are open to the objection that in case of any accident to the breast manway, by which the flow of air, shown by the arrows, is obstructed, there is no means of isolating the breast in which the accident occurs, and the ventilation of all the breasts beyond it is entirely stopped. To overcome this, sometimes the pillar *A*, shown in left-hand breast, Fig. 28, is left in each breast to protect the airway.

Rock-Chute Mining. Fig. 29 shows a section of two seams, separated by a few yards of rock. Chutes from $4\frac{1}{2}$ to 7 ft. high and 7 to 12 ft. wide are driven in the rock from the gangway or level *g* to the level *l* in the seam above, at such an angle that the coal will gravitate from the upper seam into the gangway *g*. The working, otherwise, is similar to that previously described.

FIG. 30.

Rock-chute mining contemplates the following sequence of operation:

1. The opening of all gangways and airways in the lower seam, to develop coal as yet untouched in a thick seam lying a few feet above it.

2. Developing the thick bed by a regular series of *rock chutes* driven from the gangway below; workings being opened out from chutes as in ordinary pillar-and-breast working—the panel system or some other plan may be found better than pillar-and-breast workings.

3. Driving the breasts to the limit of the lift and robbing out the pillars from a group of breasts as soon as possible, even if a localized crush is induced.

4. After one group of breasts is taken out and the roof has settled, opening a second series of chutes for the recovery of coal from any large pillars that were not taken out when the crush closed the workings.

5. While the work of recovering the pillar coal is in progress, a second group of breasts may be worked, and the process continued until all the area to be worked from that gangway has been exhausted. The same process is employed in opening lower lifts.

6. When all the upper bed of coal has been exhausted, the lower seam may be worked by the ordinary method. Workings in this seam may be

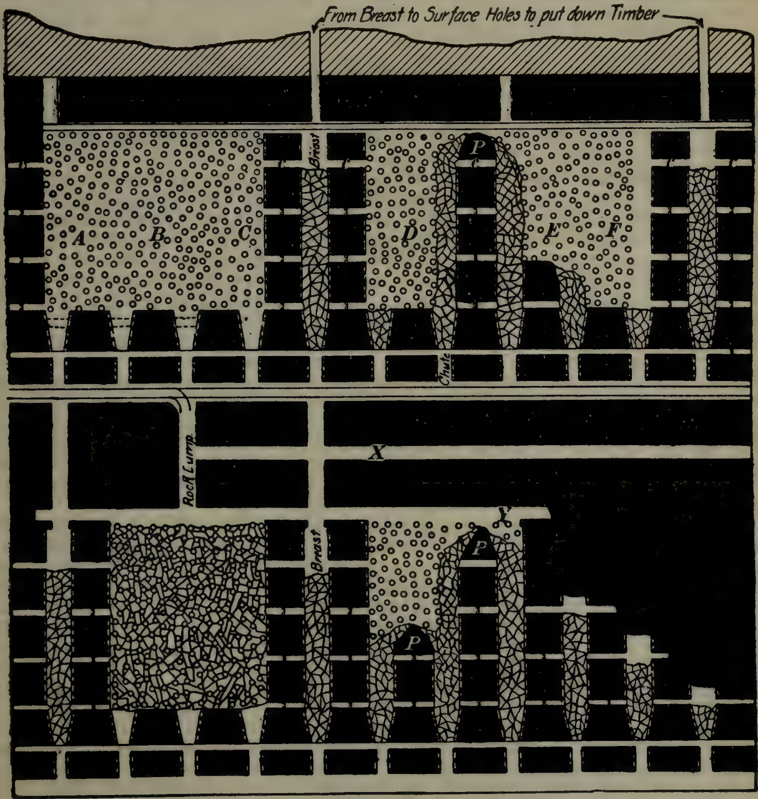


FIG. 31.

carried on simultaneously with the upper bed, but to avoid the possibility of a squeeze destroying these workings, very large pillars must be left. After exhausting the upper seam, these pillars may be advantageously worked by opening one or two breasts in the center of each, and when these are worked to the upper limit, attacking the thin rib on each side, commencing at the top and drawing back.

When the roof of the lower bed is good, the cost of timbering and keeping open the gangways and airways will be considerably less than if these were driven in the upper seam, and this difference, in some cases, may be sufficient to pay for driving all the rock chutes.

There are three undetermined points in this connection, viz.: (1) The

maximum distance between the two beds, or the length of rock chute that can be driven with satisfactory financial results. (2) The maximum dip on which such working can be successfully opened. (3) The maximum thickness of the upper and also of the lower seam, which will yield results warranting the additional outlay when rock chutes are of considerable length.

Fig. 30 shows how one or more seams are worked by connecting them by a "stone drift," or "tunnel," driven horizontally across the measures, through which the coal from the adjacent seams is taken to the haulageway leading to the landing at the foot of the slope or shaft. Tunnels are sometimes driven horizontally through the measures from the surface, so as to cut one or more seams above water level.

The lower seam of coal is worked from a gangway or level *l*, connected by a tunnel, or stone drift *t*, to the level or gangway *g*, in the thick seam. The stone drift may be extended right and left to open seams above and below the thick seam. This tunnel, or stone drift, is never driven under a breast in the upper seam, but directly under the middle of the pillar.

In the upper and thicker seam, when the coal is very hard, a breast *b* is worked to the limit and the loose coal nearly all run out through the chute *s* into the gangway *g*. The "monkey gangway" *m* is driven near the top as a return airway, and is connected to the upper end of the chute *s* by a level heading *n*, and to the main gangway *g* by a heading *v*. These headings are driven for the purpose of ventilation and to provide access to the battery in case the chute *s* should be closed. In the lower seam, the breast is still being worked upwards in the ordinary way.

The **J. L. Williams method** of working anthracite, Fig. 31, has been applied successfully by the originator at the Richards Mine, Mt. Carmel, Pa., and by it 90% of the available coal is said to have been obtained. The method is a pillar-and-stall method with the following distinguishing points: (*a*) Timbering the gob with props set not more than 6 ft. apart, to keep up the roof during the extraction of the pillars. (*b*) Making holes from the crop, for the delivery of timber into the workings. (*c*) Removing the pillars in shorter lifts than is possible when the roof is supported with culm pillars. (*d*) Keeping the gob open with timber for dumping the fallen rock, that would have to be sent to the surface if the breasts were flushed.

Both the floor and the roof of the mine were weak, so that it was not possible to make either the breasts or the pillars wide. In some cases, the floor consisted of 3 ft. of clod, and to prevent its lifting and sliding, every alternate prop was put through the clod and its foot set in the slate beneath, while the other props were set on pieces of 2″ plank 2 ft. in length to keep down the bottom. A small gangway *X* is driven to take out the chain pillar, and *Y* is a small gangway for taking in timber.

Running of Coal.—In large seams, when the coal is soft and shelly or slippery, and lies at an angle of more than 50°, and generates large quantities of firedamp, a danger to be guarded against is the sudden liberation of gas should a breast *run;* that is, should the coal at the face loosen and run out by its own gravity, only stopping when it chokes or fills up the open space below. To meet these conditions, the air-course may be driven above the gangway and used as a return, the fan being attached as an exhaust, and the working breasts ventilated in pairs. The inside manway of one of a pair of breasts is connected with the gangway for the intake, and the outside manway of the other breast with the return airway, giving each pair of breasts a separate split of the current. In collieries where this system of working is followed, the coal is soft. A new breast is worked up a few yards, but as soon as it is opened out, the coal runs freely and the manways are pushed up on each side as rapidly as possible, to keep up with the face. Two miners, one on either side, sometimes finish a breast without being able to cross to each other. The work is done exclusively with safety lamps, and when a breast "runs" the gas is liberated in such quantities that it frequently fills breasts from the top to the airway before the men can get down the manway on the return side. When the gas reaches the cross-hole, it passes into the return airway without reaching any part where men are working. Should a run of coal block a breast by closing the manway, it affects the current of one pair of breasts alone. As the gangway is the intake, leakage at the batteries passes into the breasts, as the cross-holes are above their level and the gas is thus kept above the starter when at the draw-hole. The gangway, chutes, and airway are supplied by wooden pipes, which connect with a door behind the inside chute. If a breast runs up to the surface, it does not affect the return airway, as it is in the solid.

Among the disadvantages urged against this system of working are the following:

It increases the friction, as the air must pass in the airway all the distance from the breast to the fan, the area of the airway being small in comparison to the gangway or intake.

As the faces of the breasts are so much higher than the return airway, the lighter gas must be forced down into the return against the buoyant power of its smaller specific gravity.

The reduction of friction obtained by splitting is neutralized by each split running up one small manway and down another; the advantage of running through several pillar headings and thus securing a shorter course being lost. This can be partly obviated by ventilating the breasts in groups, but the dangers avoided in splitting are increased.

Blackdamp, which accumulates in the empty or partly empty breasts, works its way down and mixes with the intake current, as there is no return current in the breast strong enough to carry it away, the return being closed in the airway.

All things considered, when the seam is soft and has a pitch of 40° and upwards, and emits large quantities of gas in sudden outbursts, as in running breasts, this system is the best that can be adopted.

When the Coal Is Hard and Gas Is Not Freely Evolved.—The reverse of the system just described is followed at some collieries where the coal is hard and but little gas is encountered. The airway is driven over the gangway or against the top, the fan being used to force the air inward to the end of the airway. The air is distributed as it returns, being held up at intervals by distributing doors placed along the gangway.

Among the advantages claimed for this plan are the following:

As the pressure is outward, it forces smoke and gas out at any openings that may exist from crop-hole falls or other causes.

The warm air from the interior of the mine returning up the hoisting slope or shaft prevents it from freezing.

As the current is carried from the fan to the end of each lift without passing through working places, the opening of doors as cars are passing, etc. does not interfere with the current.

If a locomotive is used, the smoke and gases generated by it are carried away from the men toward the bottom. Locomotives are generally used only from the main turnout to the bottom.

An objection to this system is that the gangway, as the return, is apt to be smoky. Starters and loaders are forced to work in more or less smoke, and even the mules work to disadvantage, while if gas is given off, it is passed out over the lights of those working in the gangway.

However, in places where there is but little gas, and airways of large area can be driven, this plan works very satisfactorily, and some of the best ventilated collieries are worked upon it.

An objection advanced by some against forcing fans is that they increase the pressure, thus damming the gas back in the strata. In case the speed of the fan is slacked off, the accumulated gas may respond to the lessened pressure and spring out in large volumes from its pent-up state. This argument, however, works both ways. An exhaust fan running at a given speed is taking off pressure, and if anything occurs to block the intake, the pressure is diminished, and the gas responds to the decrease on the same principle.

Hints for the Smaller Seams When They Are Small and Lie From Horizontal to About 10°.—Two gangways may be driven, the lower or main gangway being the intake. Branch gangways should then be driven diagonally or at a slant, with a panel or group of working places on each slant gangway. Large headings should connect the panels. In this system, the air is carried directly to the face of the gangway and up into the breasts, returning back through the working places. The intake and return are separated by a solid pillar, the only openings being the slant gangways on which are the panels.

The advantages of this plan are several:

The main gangway is solid, with the exception of the small cross-holes connecting with the gangway above; these furnish air to the gangway and are small and easily kept tight. These stoppings should be built of brick, and made strong enough to withstand concussion.

A full trip of wagons can be loaded and coupled in each panel or section without interfering with, or detaining the traffic on, the main road; one trip can be loaded while another is run out to the main gangway for transportation to the bottom.

The only break in the intake current is when a trip of cars is taken out from, or returns to, a panel or section; this can be partially provided against by double doors, set far enough apart to permit one to close after the trip before the other is opened. This distance can be secured by opening the first three breasts on a back switch above the road through the gangway pillar, or by running each branch over the other far enough to obtain the distance for the double doors.

If it is not desired to carry the whole volume of air to the end of the airway, a split can be made at each branch road. These will act as unequal splits in reducing friction, and, although not theoretically correct, are preferable to dragging the whole current the full length of the workings.

The objections urged to this plan are that it involves too much expense in the large amount of narrow work at high prices necessary to open out a colliery, that it necessitates a double track the whole length of the lift, and that the grade ascends into each panel or section. But the latter criticism falls, because the loss of power hauling the empty wagons up a slight grade is more than made up by the loaded wagons running down while the mules are away putting a trip into another panel or section.

For a large colliery this is without doubt the best and cheapest system.

When the Seam Is Small and Lies at an Angle of More Than 10°.—In small seams lying at an angle of more than 10°, and too small to permit an airway over the chutes, it is more difficult to maintain ventilation. If air holes are put through every few breasts, and a fresh start obtained by closing the back holes, or if an opening can be gotten through to the last lift as often as the current becomes weak, an adequate amount of air can be maintained, because the lift worked can be used as the intake, and the abandoned lift above as the return. To ventilate fresh ground, the filling of the chutes with coal will have to be depended on, or a brattice must be carried along the gangway. This can be done for a limited distance only, as a brattice leaks too much air. As a rule, collieries worked on this plan are run along until the smoke accumulates and the ventilation becomes poor; then a new hole is run through and the brattice removed and used as before for the next section. This operation is repeated until the lift is worked out. Sometimes, to make the chutes tight, canvas covers are put on the draw holes, but as they are usually left to the loaders to adjust, they are often very imperfectly applied. Then, as the coal is frequently very large, the air will leak through the batteries.

This plan works very satisfactorily if the openings are made at short intervals, say as frequent as every fifth breast, but the distance is usually much greater to save expense. As the power of the current decreases as the distance between the air holes is increased, good ventilation is entirely a question of how often a cut-off is obtained.

An effective ventilation could be maintained in a small seam at a heavy angle by working with short lifts, say two lifts of 50 yd. instead of one of 100 yd., as at present. The gangways should be frequently connected, and one used as an intake and the other as a return. This would necessitate driving two gangways where one is now made to do, but the additional expense would be made up in the greater proportion of coal won.

FLUSHING OF CULM.

From 15% to 20% of the coal taken out of an anthracite mine, according to the methods used in the past, became so fine in the course of preparation through the breaker that it could not be used or sold, and had to be piled away as refuse. Recently, the coarser portions of these culm piles have been screened out and sold for use as steam sizes, while the finer part, together with the fine material from the breaker, has been carried back into the mines with water to fill the abandoned portions of the underground workings.

This culm is carried through a system of conveyors to the hopper, usually an old oil barrel, and the stream of water is conducted into the same hopper by a 3″ pipe. The culm is then carried by the water through a pipe from 4 to 6 in. in diameter, which passes into the mine through the shaft, bore hole, or other opening, thence along the gangways to the chambers through the cross-cuts, and to the point where it is desired to deposit the culm. The bottoms or outlets of the chambers to be filled are closed by board partitions fitted closely, or by walls of slate or mine rubbish. The culm, as it issues

from the end of the pipe, takes a very flat slope, and it is carried a long distance by the water, which ultimately filters through the deposited culm to the lower portion of the mine, to be pumped to the surface. When the chamber is filled to the roof, the pipe is withdrawn and extended to the next place to be filled, and so on. Wrought-iron pipe is said to be the best, and the life of the pipe depends on the nature of the water used and the material treated. With fresh water and small culm from the buckwheat screen, it lasts 18 months; when carrying culm from the bank, ranging from dust to pea coal and some chestnut, 9 months; and when mixed with ashes, 6 months. The smaller the material the better.

The amount of water used depends on the distance to which the culm is carried and the slope of the pipe.

From $1\frac{1}{2}$ to $1\frac{3}{4}$ lb. of water is required to flush 1 lb. of culm to level and down-hill places; 3 to 6 lb. of water to 1 lb. of culm to flush up-hill for heights varying from 10 to 100 ft. above the level of the shaft bottom. Any elevation of the pipe very materially increases the amount of water necessary. Mr. James B. Davis, superintendent of the Dodson and Black Diamond mines, has ascertained by experiment that 1 cu. ft. of anthracite coal ground to culm can be flushed into a space of nearly $1\frac{1}{3}$ cu. ft., and it is therefore impossible to compress the culm more than one-third. In addition to acting as a filling and a support, to prevent squeezes and crushing, flushing has been advantageously used for fighting and sealing off mine fires. No instance has been recorded where spontaneous combustion has taken place in the flushed culm.

The Dodson culm plant, which was a pioneer, cost $7,473.42, with the capacity of flushing 119 tons per day, while the Black Diamond culm plant is capable of flushing 287 tons per day and cost $6,280.12, but plants can probably be put up much more cheaply than this.

The saving from the flushing of culm over depositing it on the surface varies for the ordinary anthracite colliery from $5 to $15 per day. The average cost of putting in stoppings in a 9′ vein is given by Mr. Davis as $9.50, including material.

To remove the pillars after the intervening breasts have been filled with culm, the face of the pillar along the gangway is attacked, and a road driven up through the pillar, splitting it (*z*, Fig. 32). This road may be the full width of the pillar, but in general it is necessary to leave a narrow stump of coal on either side to keep up the fine flushed material in the adjoining breasts. The thickness of this supporting coal depends entirely on the condition of the flushed material behind it. If that is fine, it will set firmly and form a compact mass that will not run. In such a case, the pillar may be entirely taken out, leaving a vertical wall of solidly packed flushed culm. When the flushed material is of a size larger than buckwheat, it will not set compactly, but will run when it is opened up, and when such material fills the adjoining breasts, the thin pillar of coal must be left to keep back the culm. Timbers are placed flush up against the culm or the coal stumps, as the case may be, and if there is a tendency for the culm to run, lagging is placed behind the timbers. In some cases, as much as 700 ft. of timber have been used per 100 ft. of pillar taken out. As the pillar is removed, the top settles until it finally rests upon the flushed culm, and as the weight from the top and the pressure from the sides comes upon these props, they are broken, while the coal that has been left will also be crushed. At the Black Diamond colliery, the props used are 16 ft. long, and at this colliery the top settles about 4 ft. if the flushed material is packed tightly before the roof pressure comes on it. After this settling, new props 12 ft. in length are put in close up against the culm and the broken stump of the original pillar, and they serve to keep the road open up to the working face.

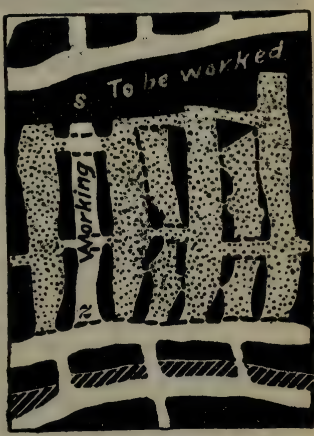


FIG. 32.

METHODS OF MINING MINERAL DEPOSITS.

Much of what has already been given under the heading of Coal Mining applies equally to the mining of mineral deposits. It will therefore not be repeated under this heading, and the only methods here given will be those that have not already been covered.

Highly inclined deposits are mined out as follows: Horizontal passages called *drifts*, *levels*, or *galleries* are driven through the ore at regular intervals, and connected by openings at right angles to the levels, which, in the case of perpendicular or highly inclined deposits, are called *winzes* or *raises*, according as they are sunk from above or raised from below. These parallel openings divide the ore body into a series of rectangles, thus serving to test its value. (See also Overhand-Stoping Method, page 304.)

Levels.—The distance between the individual levels depends on the material being mined. They are placed nearer together in high-grade ore than in low-grade material. The width of the vein also has considerable influence on the distance between the levels. In veins where it is necessary to break into walls to afford working room in the levels, they are usually placed as far apart as is consistent with the economical handling of the material in chutes and convenient access to the working faces of the stopes. The distance between the levels varies from 60 to 100 ft., and should be measured on the dip and not perpendicularly.

Winzes or Raises.—The distance between the raises or winzes varies from 30 to 250 ft., depending largely on the character of the material and the

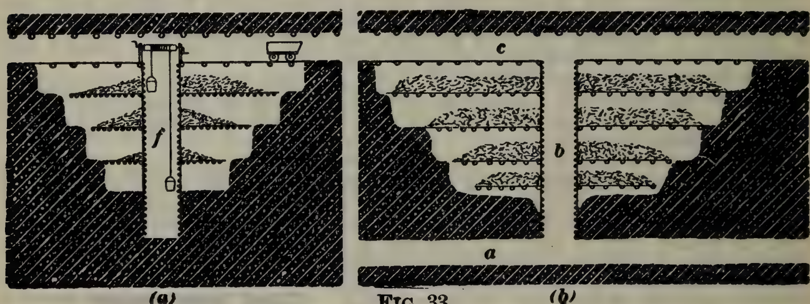


FIG. 33.

method of getting it into the chutes or winzes. Where the material at the working faces is shoveled or thrown directly into the chutes, they are often placed as close as 30 ft., while if the material is carried from the working face to the chute or winze in a wheelbarrow, the chutes may be much farther apart.

Stoping.—For narrow deposits, there are two general styles of stoping in regular use, called, respectively, *underhand* and *overhand stoping.* There are several minor divisions under each.

Underhand stoping may be conveniently divided into *underhand regular* and *underhand Cornish.*

The regular method of underhand stoping is illustrated in (a), Fig. 33, and may be described as follows: The miner selects a place in any given level or on the surface of the ore deposit from which to commence stoping. A cut 6 or 7 ft. in depth and from 6 to 8 ft. in length is made. This forms the first, or No. 1, bench in the stope. After this, he continues the work in each direction, supporting the track, if any exists above, upon stulls or timbering. After this No. 1 bench has proceeded a sufficient distance, he starts a similar cut in the bottom of it, which forms No. 2 bench, and is driven in both directions as before. At first the ore can be shoveled to the level above, but after considerable depth has been attained, it will be necessary to provide a winze, as shown at f, through which the ore from the lower benches can be hoisted. Stulls covered with lagging are placed across the stope behind each bench as platforms, to support the waste material. Underhand stoping by the Cornish system is illustrated in (b), Fig. 33, and differs from the system just described only in that the level below has to be driven first, and a winze sunk to it. a is the lower level, b the winze, and c the upper level. The work is then carried on in successive benches, as described.

The advantages of the Cornish method are that any water that collects in the stope flows to the lower level and does not have to be taken care of in each individual stope. Also, the ore can be tumbled down through the raise to the lower level, thus avoiding the extra hoisting with a windlass, or small hoist.

The *advantages* that apply to any system of underhand stoping are as follows: The ore can be extracted at once; while the stope is new, the miner is protected from the roof by stulls and stagings; the loss of fine and valuable mineral is reduced, owing to the opportunity for sorting afforded during the handling of the broken ore.

The *disadvantages* are as follows: The manner in which the ore must be handled is expensive; an individual pumping plant will be necessary in each stope of a wet mine with the regular system; should the mine be abandoned for any length of time, the stulls become loose and allow the rock stowed upon them to fall on the face of the ore, rendering the mine unsafe, and burying the ore so as to require a large expenditure of time and money to reopen the workings; in a wet stope, the water flows down over the working faces, interfering with the workmen and forcing them to stand continually in water.

Overhand Stoping.—In this system of stoping, the ore is broken down from above as the work progresses. Work is usually started from the bottom of a raise, as *B*, Fig. 34. After the lower level *A* has been driven, the miner stands on top of the lagging over the caps and works out a slice *C* 5 or 6 ft. high, this being followed by succeeding slices, as *D* and *E*. Chutes are timbered or cribbed at intervals, through which the material may be thrown down and any waste packed in the space between the chutes, as at *F*. In cases where the entire deposit is of value, a portion of the broken ore is allowed to accumulate as a platform upon which the men stand while

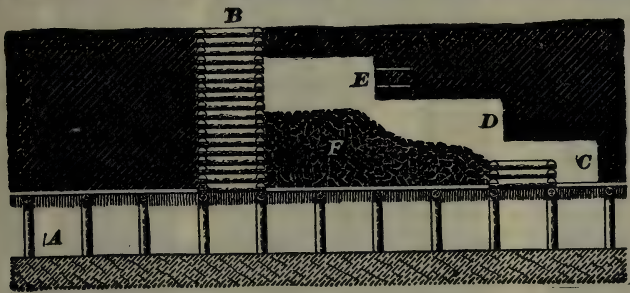


FIG. 34.

working, only enough being sent through the chutes to provide working room. After overhand stoping is started, the work may be carried on by means of breast holes, as shown at *E*. The force of gravity assists in breaking the rock, and reduces the powder necessary for blasting.

Where rich ore is broken, platforms of planks, or sheets of canvas or bull hide covered with plank, may be placed over the filling to receive the broken ore, thus preventing the loss of fine and valuable material in the filling. One argument which is usually presented against overhand stoping is that the roof is not secured by timbering, but this is offset by the fact that the workmen are always close to the roof and thus examine its condition and break off any dangerous portions or give them such support as may be needed with temporary timbers.

Overhand stoping may be carried on in a number of modified forms, all of which involve the principle of breaking down the material in such a manner that the work is aided by gravitation. Sometimes, where practically the entire deposit is removed, temporary platforms supported on stulls are constructed close to the working face for the workmen.

The *advantages* of overhand stoping are that no hoisting or pumping is required in the block of ore being worked, as with underhand stoping without a winze; water gives no trouble in the stopes; less timbering is required than in the underhand stoping, because no platforms are required to store waste, and the timbering in working stagings is usually recovered; where the mine is abandoned for a time, the working face is usually left in better

shape with overhand than with underhand stoping. In the overhand system, gravity assists in the breaking of the ore.

The *disadvantages* are that the miner is forced to work under an unsupported roof, though the fact that he is close to it enables him to examine it and take care of any dangerous portions. There may be greater loss of the fine and valuable material that becomes mixed with the waste than in underhand stoping, though this may be largely prevented by the use of boards or canvas.

Flat or Slightly Inclined Deposits.—Where flat or slightly inclined ore bodies are being worked, the working drifts (corresponding to levels in steeper deposits) are driven comparatively close together (about 30 ft. apart) and the material between them removed in successive steps, as in underhand or overhand stoping, the space behind the miner being packed with waste material to support the roof, or the roof being supported by timbering until the ore is removed. Sometimes pillars of ore have to be left to aid in the support of the roof, and when this is the case, the miners try to leave the pillars where the ore is low grade. When a deposit of ore is of uniform value throughout, and the roof of a somewhat flexible character, it may be let down without much, if any, stowing, as in the longwall system of coal mining. In other cases, the material is removed like square work or by pillars and rooms, the pillars in either case being robbed as closely as possible before leaving the workings.

LARGE DEPOSITS OVER 8 FEET THICK.

With a deposit much over 8 ft. in thickness, it is impossible to keep the walls in place by stulls or single sticks of timber. Large masses of mineral frequently contain very valuable material, and engineers have developed a number of methods for the removal of their valuable contents. The method depends largely on the value per ton of the material being removed, and local conditions as to the cost of labor, timber, filling material, character of wall rock, etc. The methods used for these deposits are *square work, filling, caving,* and *square-set timbering systems.*

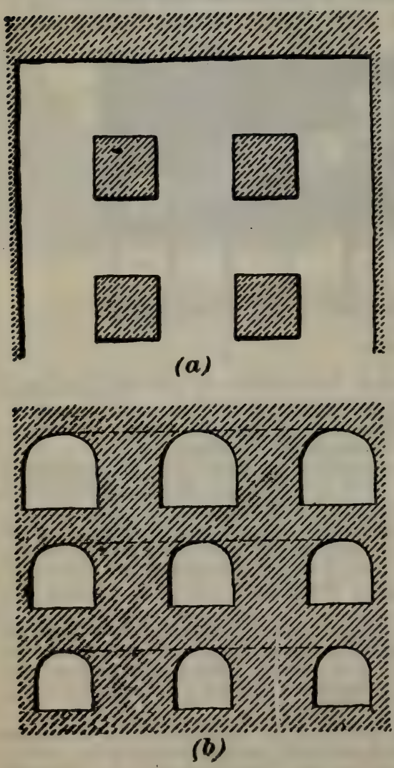


Fig. 35.

Square work, also called the *chamber-and-pillar system*, is illustrated in Fig. 35. Galleries are driven through the ore as shown, the deeper galleries being smaller than the upper ones, the object being to leave larger pillars for the support of the material above the workings. Galleries are then driven at right angles to these, to leave square pillars, as shown. When this system is applied to a bed that is only 30 or 40 ft. thick, from three-fourths to eight-ninths of all the material in the deposit can be removed, the remainder being left as pillars; but where it becomes necessary to leave floors between the succeeding levels, as shown in (*b*), Fig. 35, scarcely one-half of the deposit can be removed, even when it is of such a firm nature that the galleries can be driven considerably wider than the thickness of the pillars. This system of mining is applied to the removal of salt, gypsum, building stone, and various low-grade ores, and is very similar to the room-and-pillar system (see page 280).

The *advantages* are that it requires no timbering, and that, owing to the

larger size of the chambers, the material can be removed at a low cost per ton. The *disadvantages* are that a large portion of the deposit has to be left untouched, and that where the formation being mined is at all soft, it is not safe to work these large chambers.

Filling Methods.—Sometimes a filling of worthless material is substituted for the worked-out ore. This system may be carried on by any one of a number of different plans.

Slicing Method.—In some cases, comparatively small drifts or chambers (from 6 ft. × 6 ft. to 10 ft. × 10 ft.) are driven through the ore across the deposit, and then tightly packed with broken rock, after which other drifts or chambers are driven beside the first ones and also packed or filled. This process is continued until a slice has been removed from under the entire deposit. The process is then repeated on top of the filling, taking out successive chambers and filling them, until another slice has been removed. This method has been used in the copper mines of Spain, and has also been tried at some mines in the United States with varying degrees of success,

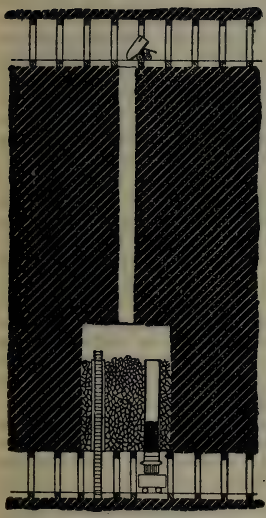


FIG. 36.

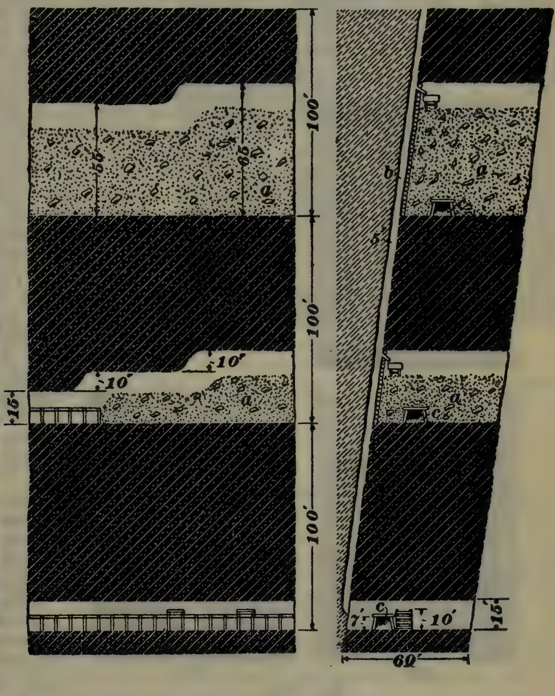


FIG. 37.

depending principally on the cost of the stowing material compared with the value per ton of the deposit being removed. In this process, the filling material should be composed entirely of large pieces, so that it can be packed closely.

Transverse Rooming With Filling.—In other cases, a filling system is used in which rooms or chambers are driven across the deposit and then continued upwards by overhand stoping, the ore being thrown to a lower level through a chute cribbed up as the work progresses, and the excavated space filled up with broken rock brought down through a chute from above, as shown in Fig. 36. After the rooms are worked out between two levels, the pillars are removed in the same manner.

Longitudinal Back Stoping With Filling.—In this case, the deposit is worked as a series of overhand stopes, Fig. 37, the space below the workmen being filled with broken rock *a* brought down through raises *b* from above, the ore being thrown to a level *c*, which has been timbered through the filling material on

the first or lower floor of the stope. This method has been very successfully applied to some of the large iron mines of the Lake Superior region of the United States.

The filling material used in any one of the various filling methods may be obtained at the surface, may be partially or wholly obtained from the waste rock associated with the vein material and from drifts or passages that have to be driven in barren ground, or it may be obtained by driving drifts into the hanging wall, and opening chambers there, from which the waste may be obtained. (See also Flushing of Culm, page 314.)

Caving Methods.—The longwall method of mining coal is really a caving system, but where this system is applied to the mining of large masses, it becomes necessary to introduce some special features. There are two general systems in use, *caving a back of ore* and *caving the gob or waste only*.

Caving a Back of Ore.—In this system, drifts or levels are run through the ore a few feet below the top of the deposit, as though the material above were to be removed by overhand stoping, but in place of breaking the material down, it is allowed to cave by gravity. When a back of ore is thick (20 ft. or more), the entire stope is sometimes allowed to cave full and then the broken ore removed by driving heavily timbered drifts through to the farther side and drawing the crushed material into the face of the drift. When the overlying worthless material appears, operations are continued by removing the last set in the drift and drawing the ore from nearer the shaft. This method is continued until practically all the broken ore has been removed. Where the back of the ore is comparatively thin (less than 20 ft.), the caving is usually accomplished at the face of the drift only, the drift being driven a short distance beyond the timbering without support. The ore above this unsupported portion will cave in and can be removed. When the waste rock and old timber from above appear, the operator retreats, removing one set of timber from the drift, caving and removing the ore over it. In this manner, operations are continued until all the ore over the drift or stope has been caved, when another drift or stope is driven beside the first and the ore over it caved. In this method, blasting has to be resorted to only in driving the drifts, from one-half to three-fourths of the ore being obtained without the use of powder.

The *advantages* of this system are that little blasting is required; practically the entire deposit is recovered; the mining cost per ton is very low.

The *disadvantages* are that the ore is liable to become mixed with more or less dirt, which caves down with it; only one level of the mine can be operated at a time, and the surface of the ground is allowed to cave into the openings, thus rendering it unfit for ordinary surface uses.

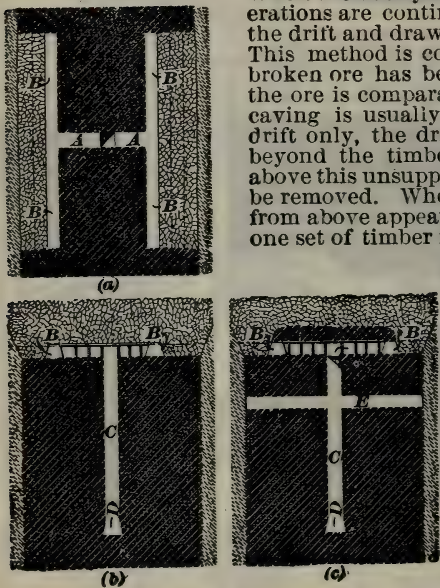


FIG. 38.

Caving the Waste Only.—In this system, Fig. 38, drifts *A* and galleries *B* are driven through the top of the ore body immediately under the waste rock. After one of these drifts or galleries is completed, the floor is covered with a lagging of plank or poles, and the waste material allowed to cave on to this platform. Subsequently, other drifts are driven beside the first one, the floor covered with lagging, and the waste allowed to cave. This process is continued until a slice has been removed over the entire surface of the ore deposit, when more drifts are driven lower down and another slice removed. After the first slice has been removed, the broken or waste material is supported on the lagging laid on the floors of the first drifts, and hence the miners have only to support this lagging in order to support the waste. The caving of any individual drift crushes the ore on either side to a considerable extent, thus materially reducing the blasting expense.

The *advantages* of this system are that the entire deposit is recovered; little blasting is required; the ore obtained is clean; the mining expense is comparatively low per ton.

The *disadvantages* are that only one level of a mine can be producing at a time; the surface is allowed to cave, thus rendering it unfit for surface uses.

SQUARE-SET SYSTEM.

Frequently, large masses of material are encountered, which it is necessary to remove, and at the same time support the surrounding material. At times, it is not desirable to fill the stope while the ore is being removed, and, at the same time, it is impossible to support the walls by single sticks or stulls. To overcome these difficulties, the square-set system has been evolved, which consists in the supporting of the walls by means of a series of square frames, from 6 to 9 ft. square, which are placed in position as fast as the ore is removed. The use of these frames reduces the length of the individual sticks, and so produces a firm structure. The timbers may be square-sawed material or round logs. If the walls are soft, the sides and top may require lagging, and if the floor is soft or composed of ore, sills will be necessary under the posts. The mining is carried on by overhand-stoping system, removing one block at a time and replacing it with the square set. Fig. 39 represents a stope, the walls and roof of which are supported by square sets that are lagged from the outside. In this case, the square sets are made from round timber.

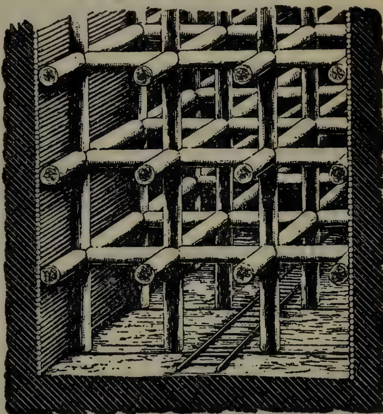


FIG. 39.

IRREGULAR DEPOSITS.

Coyoting, or Gophering.—Bodies of valuable material frequently occur that cannot be mined by any regular system. These are recovered by simply following the ore throughout its irregularities and removing it with the use of as little supporting timber or other material as possible. Owing to the crooked and irregular passages that occur in such mines, the work has been called *coyoting*, or *gophering*. Sometimes regular levels are driven at stated intervals, and the coyoting, or gophering, carried on from them. Many of the small gold and silver mines of the West, the mines of Mexico and South America, and the Missouri lead and zinc deposits are worked by this system, the object being to remove as much of the ore as possible without the use of timbering or the driving of unnecessary passages.

Probably one of the best examples of working irregular deposits is the mining practice in the Joplin zinc district, Missouri. The deposits of zinc blende are irregularly distributed through a limestone rock, and the mining is carried on in a very crude and irregular fashion.

After an ore body has been found by drilling, a shaft 5 ft. × 5 ft. to 6 ft. × 9 ft. in the clear is sunk by the contractor, the price being $4 per foot for soft and $9 per foot for hard ground for the first 50 to 80 ft., the contractor doing all the work in sinking and timbering. Through the soft ground, the shaft is timbered by 4″ round poles or by 2″ × 4″ or 2″ × 6″ timbers laid flatwise, skin to skin. The mines are divided into four kinds. (1) Very hard mines that require all the ore to be drilled with air drills and blasted out, and require no timbering. (2) Mines that are hard but have open crevices between the strata where a hand drill can be driven and a charge of dynamite lodged and exploded, throwing down a large amount of dirt and so jarring the surrounding ground that it may be easily cut down with the miner's pick. This kind of ground needs no timber. (3) Mines that are moderately soft and where the miner can place a blast anywhere by driving

a spud, throwing down a large amount of ore. The drifts are carried 10 ft. × 12 ft. in the clear, and are cut ahead from 6 to 10 ft. before putting in the sets of timber and laggings to hold the roof. (4) Mines that are very soft and where a drift cannot be carried over 8 ft. × 10 ft. in size, where the getting of the ore is all performed by pick and shovel, and where it is necessary to timber close and drive spiling overhead as well as along the sides and to resort to mud-sills in the floor of the drift.

When the shaft reaches the ore and the drift is extended for some distance to prove the ore body, underhand stoping is used and 15′ holes are drilled by hand in the bottom. A charge of 50 lb. of 40% dynamite lifts a stope 10 ft. × 10 ft. The cost of 75 tons of ore, hoisting it and dumping it on the mill platform during a shift of 9 hours in the two classes of hard mines mentioned, is, according to Mr. E. Hedburg, as follows:

1 ground boss	$ 2.50
2 miners at $2.00	4.00
2 miners at $1.75	3.50
2 shovelers at $1.75	3.50
1 hoister	1.75
1 engineer, who also sharpens picks and drills	2.25
1 engineer	1.50
Dynamite	6.00
Fuel	2.50
Oil and supplies	2.50
Superintendent	3.50
Total	$33.40

Or 44.5 cents per ton of rough ore; this includes pumping the mine.

In very soft ground, a drift 8 ft. to 10 ft. high is driven, a spiling put in the top and sides. When one level is worked out, the whole drift is then caved from the surface and allowed to settle down on the floor of timbers. The cost of mining in soft ground is about the same as in hard ore, as the saving of labor and dynamite is expended in timber and time. A typical primitive mining plant in this region, which has a shaft 150 ft. deep, with pump, hoisting engines, and boilers, and including hand jigs, screens, and tools, costs from $2,000 to $3,000; more modern plants are however now being erected, costing $8,000 to $10,000.

SPECIAL METHODS.

Frozen Ground.—When the material of placer deposits is frozen, as in Alaska and Siberia, it is mined by building a fire on the surface, which thaws the earth to a depth of from 1 ft. to 14 in. The embers are then scraped away and the thawed material removed. By repeating this operation, a shaft can be sunk, and then, by building a fire against one side, a drift can be started and continued by thawing the face, 1 ft. at a time. It has been found that 1 ft. of timber piled against the face of a drift will thaw to a depth of about 1 ft. The latest practice thaws the frozen ground by means of a steam jet instead of by fire. The openings have to be securely but not heavily, timbered.

Leaching Methods.—Salt, copper, and sulphur have been mined by leaching methods. In the case of salt, a hole is drilled into the salt formation, water allowed to flow down and dissolve the salt, and is then pumped out as a concentrated brine. For excavating upward in salt, a jet of water is made to play upon the roof of the level to be raised, and the resulting brine is carried off in launders.

When old workings containing the sulphides of copper are left exposed to the action of air and to percolating waters, part of the copper is converted into soluble sulphate. Water pumped from such mines may be a profitable source of the metal, for by passing it over iron bars or scrap iron the copper will be separated and deposited as cement copper in the bottom of the vessel containing the iron.

In the case of sulphur, superheated steam is forced down to melt the sulphur, which is then pumped out.

COSTS OF MINING ANTHRACITE.

The following costs include only labor and supplies, and do not include, in general, improvements, royalties, taxes, and other similar fixed charges that are independent of the method of mining.

LEHIGH REGION (PENNA.).

The costs for the Lehigh region, though based on the results of a single company, are believed to be very fairly representative of the entire region. They are the mean costs of two collieries where about 2,000 men were employed inside and outside, and apply to the year 1897, when the condition at all anthracite mines was very unfavorable to economical working, as the mines were then working on very short time.

The tonnage at these collieries for the year was as follows:

January,	29,775.04	May,	34,090.02	September,	27,406.94	Total, 463,672.08.
February,	30,872.97	June,	35,761.89	October,	56,710.04	
March,	42,827.04	July,	44,409.13	November,	48,177.94	
April,	38,553.08	August,	37,500.97	December,	37,587.02	

The following tables show the distribution of this output by sizes during the year, and the costs per ton itemized under the several headings given:

PERCENTAGES OF DIFFERENT SIZES.

Month.	Lump.	Broken.	Egg.	Stove.	Chestnut.	Pea.
January	10.56	23.59	18.27	18.69	14.21	14.68
February	12.34	22.54	18.11	17.98	14.50	14.53
March	11.85	19.26	18.81	19.69	13.18	17.21
April	12.81	19.21	18.35	19.48	11.14	19.01
May	13.81	19.11	18.35	19.01	11.32	18.40
June	15.29	18.60	17.73	19.08	11.23	18.07
July	14.26	19.89	17.41	18.30	11.25	18.89
August	13.56	20.26	18.10	17.72	11.49	18.87
September	12.31	20.41	18.27	18.28	11.61	19.12
October	12.21	18.01	19.15	18.89	12.28	19.46
November	11.40	18.53	19.78	19.79	12.01	18.49
December	10.78	19.56	20.09	20.32	12.07	17.18
Year	12.58	19.71	18.59	18.99	12.15	17.98

COSTS OF MINING AND PREPARATION.

Month.	Outside.			Inside.			Total Cost.	Credits.	Net Cost
	Labor.	Supplies.	Total.	Labor.	Supplies.	Total.			
January	.300	.109	.409	.951	.196	1.147	1.595	.100	1.495
February	.297	.085	.382	.909	.190	1.099	1.519	.063	1.456
March	.243	.047	.290	.844	.151	.995	1.311	.088	1.223
April	.242	.071	.313	.822	.137	.959	1.303	.075	1.228
May	.251	.100	.351	.852	.166	1.018	1.397	.103	1.294
June	.300	.079	.379	.500	.203	.703	1.576	.103	1.473
July	.240	.063	.303	.487	.162	.649	1.485	.084	1.401
August	.248	.095	.343	.709	.182	.891	1.579	.085	1.494
September	.278	.096	.374	.682	.158	.840	1.588	.054	1.534
October	.228	.093	.321	.721	.129	.850	1.580	.072	1.508
November	.247	.093	.340	.806	.210	1.016	1.846	.091	1.755
December	.290	.061	.351	.833	.220	1.053	1.883	.090	1.793
Year	.271	.092	.363	1.109	.162	1.271	1.634	.088	1.546

Cost per Ton of Supplies Used Inside.

Distribution.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.
Oils	.010	.011	.007	.010	.007	.009	.006
Powder	.033	.030	.031	.026	.030	.032	.029
Lumber	.007	.025	.011	.004	.002	.008	.007
Props	.040	.027	.021	.015	.022	.027	.019
Feed	.039	.018	.019	.017	.023	.022	.022
Mules killed, etc.	.010	.005	.014	.019	.013	.009	.015
T rails, frogs, etc.	.005	.012	.007	.009	.018	.010	.010
Wire ropes		.018	.016			.025	.013
General supplies	.019	.021	.014	.009	.018	.021	.013
Total general supplies	.166	.167	.140	.109	.133	.163	.134
Pumping machinery	.009	.005	.004	.012	.016	.023	.004
Hoisting machinery							
Ventilating machinery							
Boilers							
Mine cars	.021	.018	.007	.016	.017	.017	.024
Engines							
Total repairs	.030	.023	.011	.028	.033	.040	.028
Total cost inside	.196	.190	.151	.137	.166	.203	.162
Credits	.100	.063	.088	.075	.103	.103	.084
Net cost inside	.096	.127	.063	.062	.063	.100	.078

Cost per Ton of Supplies Used Outside.

Distribution.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.
Oils	.010	.008	.007	.006	.009	.009	.008
Lumber	.022	.025	.003	.016	.015	.005	.012
Feed	.008	.004	.005	.004	.005	.005	.006
Mules killed, etc.							
T rails, frogs, etc.			.001	.003	.004	.005	.002
Wire ropes							
General supplies	.020	.021	.015	.008	.040	.016	.019
Total general supplies	.060	.058	.031	.037	.073	.040	.047
Pumping machinery	.001						
Hoisting machinery	.008	.002	.001	.001	.003	.008	.001
Ventilating machinery						.003	
Breaker machinery	.028	.012	.008	.014	.017	.011	.008
Boilers	.006	.005	.002	.013	.001	.011	.005
Breaker	.006	.008	.005	.006	.005	.006	.002
Tracks and sidings					.001		
Miscellaneous							
Total repairs	.049	.027	.016	.034	.027	.039	.016
Total cost outside	.109	.085	.047	.071	.100	.079	.063
Credits							
Net cost outside	.109	.085	.047	.071	.100	.079	.063

In the two tables above and the one following, the figures were available for seven months of the year only, but an average for these months gives a fair average for the year.

ITEMIZED COST OF OUTSIDE LABOR.

Occupations.	Jan.	Feb.	March.	April.	May.	June.	July.
Foreman and assistants	.013	.012	.007	.006	.006	.006	.003
Clerks, shipper and supply	.004	.004	.003	.003	.002	.002	.002
Hoisting engineers	.009	.022	.018	.021	.019	.026	.021
Pump and fan engineers	.003	.003	.003	.002	.003	.003	
Locomotive engineers and helpers	.014	.014	.011	.009	.011	.013	.011
Firemen and ashmen	.078	.071	.056	.060	.063	.069	.057
Stablemen	.005	.005	.003	.003	.004	.005	.003
Watchmen	.007	.006	.004	.005	.006	.006	.004
Total miscellaneous	.133	.137	.105	.109	.114	.130	.101
Topmen and footmen	.004	.004	.002	.003	.003	.004	.003
Top drivers and oilers	.007	.007	.006	.006	.007	.008	.007
Dumpmen	.002	.003	.002	.002	.002	.003	.002
Platform and docking boss	.014	.013	.013	.012	.012	.012	.012
Chute bosses	.006	.006	.005	.006	.005	.004	.006
Slate pickers	.059	.063	.058	.053	.048	.056	.057
Car loaders	.007	.007	.007	.006	.006	.008	.008
Breaker engineer	.003	.003	.002	.002	.002	.001	.002
Dirt and plane engineer	.007	.001	.001	.001	.001	.001	.001
Rock and dirt men	.007	.009	.009	.006	.004	.005	.005
General laborers	.012	.013	.009	.011	.020	.022	.012
Total breaker	.128	.129	.114	.108	.110	.124	.115
Pumping machinery	.001	.001					
Hoisting machinery	.010	.005	.005	.005	.006	.009	.005
Ventilating machinery						.003	
Breaker machinery	.005	.004	.004	.006	.003	.002	.002
Boilers	.004	.004	.001			.005	.002
Breakers	.007	.009	.007	.005	.011	.019	.006
Tracks and sidings	.008	.007	.007	.009	.007	.008	.007
Miscellaneous	.004	.001					.002
Total repairs	.039	.031	.024	.025	.027	.046	.024
Total cost outside labor	.300	.297	.243	.242	.251	.300	.240

WYOMING REGION (PENNA.).

The following tables of costs for the Wyoming region give mean results from a number of different collieries which are quite widely separated in location and at which the conditions of working are so different that the mean results given are thought to represent average results for the entire region. They also apply, approximately, to the Lackawanna Valley, where the general conditions are the same, although the seams are much nearer the surface than in the Wyoming region, and the amount of gas present in the coal is much less. These same figures are probably also fairly representative of the Schuylkill and Shamokin fields.

The collieries for which the following figures are averages are all operated through shafts, varying in depth from 350 to 1,100 ft., and many of the mines are extremely gaseous. The number includes several entirely new and modern surface and underground plants, and the others, though not new, have been overhauled and modernized as much as possible. At these collieries 10,000 men were employed during the year 1895, for which the data are given, and during the same year the output was 1,862,144 tons, distributed during the year as follows:

Month.	Tonnage.	Days Worked.	Month.	Tonnage.	Days Worked.	Month.	Tonnage.	Days Worked.
January	107,952	7.94	May	179,752	12.84	September	161,213	11.52
February	98,109	7.37	June	164,062	11.92	October	198,161	13.90
March	141,991	9.95	July	145,445	10.59	November	228,433	17.15
April	136,375	9.69	August	177,241	12.96	December	123,406	8.87

Percentages of Different Sizes.

Month.	Lump.	Steamer.	Broken.	Egg.	Stove.	Chestnut.	Pea.
January	8.21	.02	17.53	20.31	21.46	18.04	14.43
February	8.29	.12	17.75	20.41	20.85	17.44	15.14
March	6.20	.55	17.64	20.04	20.65	18.00	16.92
April	7.01	.38	16.76	20.17	20.92	18.12	16.64
May	4.79	.27	18.63	20.33	21.42	18.23	16.33
June	3.29	.21	22.43	19.72	20.21	18.57	15.57
July	7.84	.42	19.42	19.54	19.46	18.58	14.74
August	5.05	.57	19.84	20.69	18.92	18.62	16.31
September	4.25	.27	18.81	21.98	19.98	19.32	15.39
October	4.72	.01	16.77	22.00	21.27	19.88	15.35
November	2.69	.16	15.56	22.42	22.66	20.71	15.80
December	4.40	.57	14.03	22.62	21.27	21.41	15.70
Year	5.23	.29	17.96	20.95	20.80	19.03	15.74

Costs of Mining and Preparation per Ton.

Months.	Outside.				Inside.				Total Cost.	Credits.	Net Cost.
	Labor.	Supplies.	Repairs.	Total.	Labor.	Supplies.	Repairs.	Total.			
January	.363	.042	.014	.419	.934	.249	.028	1.211	1.630	.120	1.510
February	.376	.042	.014	.432	.947	.273	.030	1.250	1.682	.104	1.578
March	.297	.031	.010	.338	.872	.182	.022	1.076	1.414	.096	1.318
April	.305	.034	.023	.362	.870	.203	.020	1.093	1.455	.103	1.352
May	.270	.022	.011	.303	.839	.164	.015	1.018	1.321	.101	1.220
June	.290	.032	.011	.333	.874	.206	.018	1.098	1.431	.105	1.326
July	.309	.046	.019	.374	.879	.266	.033	1.178	1.552	.098	1.454
August	.286	.030	.017	.333	.873	.194	.026	1.093	1.426	.102	1.324
September	.284	.039	.012	.335	.890	.201	.024	1.115	1.450	.105	1.345
October	.267	.036	.013	.316	.856	.188	.020	1.064	1.380	.100	1.280
November	.262	.029	.010	.301	.860	.214	.018	1.092	1.393	.104	1.289
December	.344	.045	.018	.407	.954	.307	.028	1.289	1.696	.120	1.576
Year	.297	.034	.014	.345	.881	.214	.023	1.118	1.463	.104	1.359

Coal Production of United States.

Year.	Bituminous.		Anthracite.	
	Tons of 2,000 Lb.	Value.	Tons of 2,240 Lb.	Value.
1890	111,302,322	$110,420,801	46,468,641	$66,383,772
1895	135,118,193	115,779,771	57,999,937	82,019,272
1897	147,609,985	119,567,224	52,611,680	79,301,954
1898	166,592,023	132,586,313	53,382,644	75,414,537
1899	193,321,987	167,935,304	53,944,647	88,142,130

PRICES OF COAL.

The table on page 327, given by the U. S. Geological Survey, will be of interest as showing the fluctuations in the average prices ruling in each State since 1886. Prior to that year, the statistics were not collected with sufficient accuracy to make a statement of average prices of any practical value. These averages are obtained by dividing the total value by the total product, except for the years 1886, 1887, and 1888, when the item of colliery consumption was not considered.

AVERAGE PRICES PER SHORT TON FOR COAL AT THE MINES SINCE 1886.

State or Territory.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.
Alabama	$1.43	$1.30	$1.15	$1.11	$1.03	$1.07	$1.15	$0.99	$0.93	$0.90	$0.90	$0.88	$0.75	$1.09	$1.17	$1.09
Arkansas	1.60	1.68	1.50	1.42	1.29	1.19	1.24	1.34	1.22	1.25	1.11	1.06	1.03	1.17	1.14	1.13
California	3.00	3.00	4.00	2.36	2.56	2.20	2.46	2.31	2.31	2.33	*b*2.35	*b*2.55	*b*2.53	*b*2.68	3.05	2.60
Colorado	2.35	2.20	2.20	1.51	1.40	1.37	1.62	1.24	1.24	1.20	1.16	1.17	1.15	1.12	1.12	1.13
Georgia	1.50	1.50	1.50	1.50	1.04	1.50	.99	.98	.85	.83	.70	.72	.81	1.00	1.17	1.20
Idaho												*c*3.33	2.57	5.00	5.00	
Illinois	1.11	1.09	1.12	.97	.93	.91	.91	.89	.89	.80	.80	.72	.78	.85	1.04	1.03
Indiana	1.15	1.34	1.40	1.02	.99	1.03	1.08	1.07	.96	.91	.84	.84	.81	.88	1.03	1.01
Indian Territory	1.60	1.87	1.88	1.76	1.82	1.74	1.71	1.79	1.59	1.43	1.40	1.34	1.32	1.43	1.45	1.61
Iowa	1.25	1.34	1.30	1.33	1.24	1.27	1.32	1.30	1.26	1.20	1.17	1.13	1.14	1.24	1.38	1.39
Kansas	1.20	1.40	1.50	1.48	1.30	1.31	1.31½	1.27	1.23	1.20	1.15	1.18	1.09	1.16	1.22	1.22
Kentucky	1.15	1.15	1.20	.99	.92	.93	.92	.86	.88	.86	.78	.79	.79	.79	.92	.95
Maryland	.95	.95	.95	.86	.86	.81	.89	.88	.77	.81	.80	.76	.76	.76	.98	.98
Michigan	1.50	1.50	1.66	1.71	1.99	1.66	1.56	1.79	1.47	1.60	1.62	1.46	1.47	1.39	1.48	1.41
Missouri	1.30	1.34	2.21	1.36	1.24	1.23	1.23	1.23	1.17	1.12	1.08	1.08	1.07	1.20	1.21	1.23
Montana	3.50	3.50	3.50	2.42	2.42	2.27	2.36	1.99	2.04	1.89	1.47	1.76	1.57	1.57	1.63	1.43
Nevada									3.15							
New Mexico	3.00	3.00	3.00	1.79	1.34	1.68	1.62	1.47	1.57	1.49	1.49	1.38	1.35	1.39	1.37	1.42
North Carolina					1.74	1.93	1.44	1.50	1.76	1.66	1.50	1.34	1.25	1.30	1.32	1.25
North Dakota	1.59	1.50	3.50	1.43	1.40	1.40	.96	1.13	1.12	1.07	1.09	1.08	1.11	1.19	1.22	1.28
Ohio	.95	.88	.93	.93	.94	.94	.94	.92	.83	.79	.79	.78	.83	.87	1.02	.99
Oregon	2.50	2.20	3.00		2.89	3.00	4.29	3.57	3.87	3.36	2.90	3.09	3.65	3.00	3.74	2.52
Pennsylvania bituminous	.80	.90	.95	.77	.84	.87	.84	.80	.74	.72	.71	.69	.67	.76	.97	.98
Tennessee	1.15	1.30	1.10	1.21	1.10	1.11	1.13	1.08	.97	.93	.86	.81	.77	.88	1.14	1.12
Texas	1.85	2.00	2.05	2.66	2.53	2.40	2.32	2.28	2.32	1.88	1.65	1.52	1.66	1.51	1.63	1.72
Utah	2.10	2.00	2.10	1.59	1.74	1.80	1.56	1.48	1.40	1.31	1.20	1.19	1.27	1.27	1.26	1.25
Virginia	1.00	.94	1.00	.93	.75	.83	.86	.84	.76	.63	.68	.67	.59	.62	.89	.86
Washington	2.25	2.20	3.00	2.32	2.71	2.31	2.28	2.31	2.33	2.16	2.00	1.94	1.78	1.78	1.90	1.65
West Virginia	.94	.95	1.10	.82	.84	.80	.80	.77	.75	.68	.65	.63	.61	.63	.81	.86
Wyoming	3.00	3.00	3.00	1.26	1.70	1.53	1.27	1.35	1.31	1.33	*c*1.37	1.21	1.28	1.24	1.36	1.35
Total bituminous	*a*1.06	*a*1.12	*a*1.00	1.00	.99	.99	.99	.96	.91	.86	.83	.81	.80	.87	1.04	1.04
Pennsylvania anthracite	*a*1.95	*a*2.01	*a*1.95	1.44	1.43	1.46	1.57	1.59	1.52	1.41	1.50	1.51	1.41	1.46	1.49	1.67
General average	*a*1.30	*a*1.45	*a*1.42	1.13	1.12	1.13	1.16	1.14	1.09	1.02	1.02	.99	.95	1.01	1.14	1.18

a Exclusive of colliery consumption. *b* Includes Alaska. *c* Includes Nebraska.

COST OF COKING COAL.

The cost for labor alone of coking coal has been given by a number of companies in the Connellsville district as 61 cents per ton of coke produced, or 40⅔ cents per ton of coal coked, exclusive of royalties, taxes, rents, and such fixed charges.

In the "American Manufacturer" for July 27, 1899, Mr. F. C. Keighley gave the following as the proportional costs of the several items of mining and coking Connellsville coal:

Coke Yard.	Per Cent.	Coke Yard.	Per Cent.
Drawing	70.01	Shifting cars	1.28
Leveling	8.96	Yard bosses	1.12
Charging	3.48	Masons on repairs	6.12
Carters	2.48	Forking	1.60
Bookkeeper and superintendent, ½ of total for mine and yard	2.04	Individual cars	.52
Cleaning tracks	1.20	Sundry	.51
		Yard pumps	.76
		Total	100.08

Mine.	Per Cent.	Mine.	Per Cent.
Room coal	52.15	Machinist	.49
Drivers	8.07	Bookkeeping, ½ of total for mine and yard	.49
Heading coal	11.15	Outside labor	2.03
Rope haulage	2.81	Stable boss	.96
Roads	3.03	Teams	.65
Mine bosses	1.31	Blacksmith	.98
Fire boss	1.44	Carpenters	1.01
Timber	2.83	Lamp cleaners	.82
Trappers	.43	Inside pumps	.59
Superintendence, ½ of total for mine and yard	.49	Steam pumps	.55
Cagers	.66	Surveys	.41
Runners and oilers	.80	Extra men	.51
Engineers	1.01	Supplies	.92
Firemen	1.13	Betterments	1.05
Dumpers	1.25	Total	100.02

The mine labor is 67.20% of the total labor cost, and the coke-yard labor is 32.80% of the total labor cost.

The cost of equipping a coke plant and opening a mine to furnish the coal in the Connellsville region is from $500 to $1,000 per oven, dependent on the kind of opening for the mine and local considerations. $500 per oven is a fair price for a plant when the conditions are favorable and the mine is a drift mine, and $1,000 is a fair price for a shaft mine about 300 ft. deep, under rather unfavorable conditions.

Fulton gives the cost of the various types of coke ovens as follows:

Not saving by-products: Beehive, $300; Thomas, $800; McLanahan, $800; Belgian, $1,000; Coppée, $1,000; Bernard, $1,000.

Saving by-products: Simon Carvès, $1,300; Semet-Solvay, $1,600; Hüessner, $1,400; G. Seibel, $1,300; Otto-Hoffman, $1,600; Festner-Hoffman, $1,500.

The usual quantity of coal required to make 1 ton of coke is 1.4 to 1.6 tons.

The loss in loading coke at the ovens and again unloading it at the furnaces or steel works is 2% to 3%. During the winter and in wet seasons coke takes on 2% to 3% of moisture in transit between the ovens and the furnaces.

EXPLOSIVES.

The characteristics of a good blasting explosive are: (1) sufficient stability and strength; (2) difficulty of detonating by mechanical shock; (3) handy form; (4) absence of injurious effects on the user.

Explosives are divided into two general classes: (1) low explosives or direct-exploding materials; (2) high explosives or indirect-exploding materials that require a detonator.

Low Explosives.—Gunpowder or black powder is the type of this group. Its composition varies, depending on the purpose for which it is to be used, but the ingredients commonly used in its manufacture are saltpeter, sulphur, and charcoal.

The following table gives the composition of blasting powder in different countries:

COMPOSITION OF BLASTING POWDER (*Guttmann*).

Ingredients.	Great Britain.	Germany.	Austria-Hungary.	France.	Russia.	Italy.	United States.
Saltpeter	75	66.0	64	62	66.6	70	64
Sulphur	10	12.5	16	20	16.7	18	16
Charcoal	15	21.5	20	18	16.7	12	20

High Explosives.—These are a mixture of nitroglycerine with an absorbing dope, the composition of which is such that, in addition to thoroughly and permanently absorbing the nitroglycerine, it is itself a gas-producing compound. Nitroglycerine at 60° F. has a specific gravity of 1.6. It is odorless, nearly or quite colorless, has a sweetish burny taste, is poisonous even in very small quantities, and is insoluble in water. All nitroglycerine compounds freeze at 42° F., and explode when confined at 360° F. It takes fire at 306° F., and, if unconfined, burns harmlessly unless in large quantities, so that a part of it, before coming in contact with the air, becomes heated to the exploding point.

Thawing Dynamite.—All frozen cartridges should be thawed, as, when frozen, cartridges are very hard to explode, and even if they do explode, the results are not nearly as satisfactory as when properly thawed. When cartridges are frozen, do not expose to a direct heat, but thaw by one of the following methods: *First*, place the number of cartridges needed for a day's work on shelves in a room heated by steam pipes (not live steam) or a stove. Where regular blasting is done, a small house can be built for this purpose, fitted with a small steam radiator. Exhaust steam through these pipes gives all heat necessary. Bank your house around with earth, or, preferably, fresh manure. *Second*, use two water-tight kettles, one smaller than the other, put cartridges to be thawed in smaller kettle, and place it in larger kettle, filling space between the kettles with hot water at, say, 130° to 140° F., or so that it can be borne by the hand. To keep water warm, do not try to heat it in the kettle, but add fresh warm water. Cover kettles to retain heat. In thawing do not allow the temperature to get above 212° F. *Third*, where the number of cartridges to be thawed is small, they may be placed about the person of the blaster until ready for use, the heat of the body thawing the cartridges. Keep cartridges away from all fires—this applies to all explosives. Do not be in a hurry, but thaw slowly. Do not thaw before an open fire. Do not put cartridges in an oven, on a hot stove, against hot iron plates, or against brick casing of a boiler. Do not put cartridges in hot water, or expose them to live steam. And do not take any kind of powder, fuse, or caps near a blacksmith shop.

A large number of high explosives are made that vary but little in their composition, the main difference being in the character of the dope and in the percentage of nitroglycerine. The trade name is usually determined by the percentage of nitroglycerine, thus 10% dynamite means that the dynamite contains 10% of nitroglycerine, etc.

Safety explosives, or as they are called in England, *permitted explosives*, are compounds intended for use in gaseous mines, and they are so constituted

that they will ignite without producing the extremely high temperature given by ordinary explosives. The term *flameless explosives* was formerly used, but it has been replaced by *safety explosives*, as the absence of a flame is not now necessary to a permitted explosive.

COMMON BLASTING EXPLOSIVES.

Atlas.		Brands Equivalent in Strength to Atlas.						
Brand.	Per Cent. Nitroglycerine.	Repauno Gelatine.	Hercules Powder.	Hercules Gelatine.	Giant Powder.	Giant Gelatine.	Hecla Powder.	Ætna Powder.
A	75	A	No. 1 XX	No. 1 XX	Old No. 1	No. 1 A	No. 1 XX	
B+	60	B +	No. 1	No. 1	No. 1 A	No. 1	No. 1 XS	No. 1
B	50	B	No. 2 SS	No. 2 SS	New No. 1	No. 2	No. 1 X	No. 2 XX
C+	45	C +	No. 2 S	No. 2 S	No. 2 Extra			No. 2 X
C	40	C	No. 2	No. 2	No. 2	No. 3 C	No. 1	No. 2
D+	33		No. 2 C		No. 2 C		No. 2 X	No. 3 A
D	30		No. 3		No. 3		No. 2	No. 3
E+	27		No. 3 B		XXX		No. 3 X	No. 3 B
E	20		No. 4 B		XXXX		No. 3	No. 4

Drilling.—Adapt the size and depth of the hole to the work to be accomplished. As a rule, for ordinary rock blasting, the distance between the holes should be equal to from one-half to the total depth of the holes, the holes set back from the face twice as far for dynamite as for common black powder, say a distance equal to the depths of the holes or slightly less, and load one-third the length of the hole. These directions are only general, and do not apply to very deep holes. Much depends on character and hardness of the rock, also on size of drill holes. In all cases, the experience and judgment of the blaster must be his guide.

Diameter of Holes.—In driving headings or sinking shafts, experience shows that holes having a diameter varying from $\frac{3}{4}$ to $1\frac{1}{4}$ in. at the bottom are most economical in hard rock, if charged with the strongest high explosive. On the contrary, holes of large diameter, say $1\frac{1}{2}$ to 2 in. in diameter, and charged with strong, low, and cheap explosive, are the best when operating in weak rock. All the holes in the heading or shaft should have the same diameter, and the best arrangement is to give an equal resistance of rock to each, and to so place each hole that it will receive the greatest benefit from the free faces formed by firing the previous holes.

Relation of Diameter of Hole to Length of Charge.—By experiment, it has been proved that, as a rule, the length of the charge of explosive for single holes should not exceed from 8 to 12 times the diameter of the hole; that is, a 1″ hole should never have a charge of more than 12 in. of explosive placed in it. Where several holes are fired together, this rule is sometimes slightly deviated from. It is usually best to employ a length of charge between these two limits, as, for instance, about 10 times the diameter of the hole.

Chambering or **squibbing** is the blasting out of a cavity at the bottom of a drill hole to allow of a larger charge of explosive being used.

Bulling a drill hole is the working of clay into any cracks opening into a drill hole, to prevent the power of the blast being scattered through these cracks.

Charging.—The charge must fit and fill the bottom of bore and be packed solid. If holes are comparatively dry, slit the paper of the cartridges lengthwise with a knife, and as each is dropped into the hole, strike a wooden

rammer on it with sufficient force to make the powder completely fill the bottom and diameter of the bore. Where water is not present, a more perfect loading is made by taking powder out of cartridge and dropping it in loosely, ram each 6 or 8 in. of the charge, using the paper of each cartridge as a wad, to take down any powder that may have stuck to the sides of the hole. If water is standing in the hole, do not break the paper of the cartridges and avoid ramming more than enough to settle the charge on the bottom, using cartridges of as large diameter as will readily run into the bore.

When cartridges are used, the last cartridge placed in the hole should contain an electric exploder, or cap with fuse attached. When loose powder is used, a piece of cartridge 2 or 3 in. in length, with exploder or cap attached, should be pressed firmly on top of charge. Some blasters put an exploder or cap in the first cartridge put in the hole, placing remainder of charge on top. The charge should be placed in a solid part of the material to be broken. If possible, the face should be undercut and then the overhanging material shot down. Best results are obtained when the bore holes cross the faces or layers of the material at right angles. The charges should be placed so as to disturb the sides and roof of a tunnel through material of medium hardness as little as possible. The charge at the bottom of the tunnel should be placed from 6 to 12 in. below the permanent level.

Amount of Charge.—No invariable rule can be laid down as to the diameter and length of cartridges to be used under any and all circumstances, nor the amount or grade of powder required for all kinds of work. Much depends on the good sense and judgment of the persons using the explosive. Guttmann, in his well-known handbook on blasting, says: "There is no lack of theories for the determination of blasting charges, but their application depends on empirical facts determined by practical work. I therefore advise that the calculation of charges under ordinary conditions be neglected, and recommend watching actual operations for some weeks, asking for explanation from the most expert miners. In this way experience will be gotten in a short time that will enable one to estimate with some precision the proper charge to use after inspecting the spot to be blasted."

A good rule by which to determine the weight of black powder to use in any given hole in bituminous workings is the following: Find the distance in feet from the charge out in the line of least resistance. Multiply the fourth power of this distance by $\frac{4}{10}$ the diameter of the hole in inches, and divide this product by the thickness of the seam in inches. The result will be the weight of the charge in pounds. Thus, for a $2\frac{1}{2}''$ hole in a seam of bituminous coal 6 ft. thick, where the charge is placed $4\frac{1}{2}$ ft. deep from the face of the coal, or cutting, we have for the weight of charge to be used,

$$\frac{9}{2} \times \frac{9}{2} \times \frac{9}{2} \times \frac{9}{2} \times \frac{.4 \times 2.5}{6 \times 12} = 5.7 \text{ lb.}$$

Tamping.—In deep holes, water makes a good tamping, but fine sand, clay, etc. are generally used. Fill in for the first 5 or 6 in. carefully, so as not to displace cap and primer; then with a hardwood rammer pack balance of material as solid as possible, ramming with the hand alone, and not using any form of hammer. Never use a metal tamping rod.

Firing.—If the work is wet, or the charge used under water, use waterproof fuse, and protect the end of the fuse by applying bar soap, pitch, or tallow around the edge of the cap. Water must not be allowed to reach the powder in the fuse or the fulminate in the cap. Exploding by electricity is best under water at great depth, as the pressure of water is so great on the fuse that it is forced through and dampens it so as to prevent firing.

Seam Blasting.—If a seam is found in the rock, remove the powder from the cartridges and push it into the seam and fire a cap beside it. This will open the seam so that a larger quantity of explosive can be used, and the rock broken without drilling. In blasting coal, slate, marble, granite, freestone, or any other material that it is desirable to obtain in large blocks, cartridges of small diameter should be used in wide bore holes, the charge being rolled in several folds of paper, to prevent its touching the sides of the bore holes. The intensity of action and the crushing effect of the explosive are thus lessened.

Firing by Detonation.—Nitroglycerine explosives always require detonation by a cap or exploder in order to develop their full force. Fig. 1 illustrates the method of attaching such an exploder to the end of a fuse and the placing of it in the cartridge. The exploders are loaded with fulminate of mercury and are slipped over the end of the fuse, after which the upper end is

crimped tightly against the end of the fuse, as shown. (Miners sometimes bite the caps on to the fuse with their teeth. This is a very dangerous proceeding and should never be allowed, as, with strong caps, one of them exploding in a man's mouth would prove fatal.) In placing the cap or

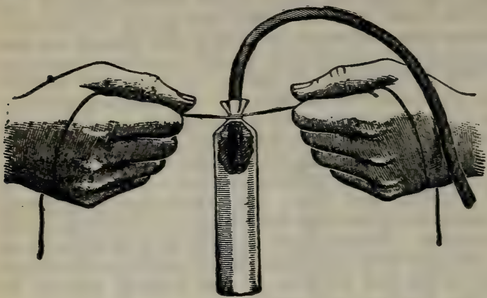


FIG. 1.

FIG. 2.

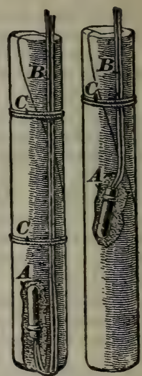


FIG. 3.

exploder into the dynamite or giant-powder cartridge, care should be taken that only about two-thirds of the cap be embedded in the material of the cartridge, for if the fuse had to pass through a portion of the material before reaching the cap, there would be danger of its igniting the material, thus causing deflagration of the cartridge in place of detonation. The fumes given off by high explosives are much worse in the case of deflagrating a cartridge.

The **electric exploder**, Fig. 2, has wires *A* and *B*, which carry the current to the exploder. *D* is a cement (usually sulphur) that protects the explosive compound *C* (usually mercury fulminate) and the whole is contained in a copper shell. A small platinum wire *E* is heated by the passage of a current and ignites the explosive. Fig. 3 shows the method of placing a cap or an electric exploder in a cartridge of powder.

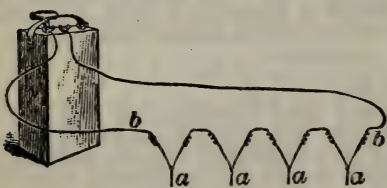


FIG. 4.

When a number of holes are exploded at one time, the electric exploders are connected in series, as shown in Fig. 4, for a small number of holes, and as in Fig. 5 for a larger number.

The battery for furnishing the current of electricity is a magneto machine that is worked by either pulling up or by depressing a handle or rack bar, or else by turning a crank.

Directions for Blasting by Electricity.—Drill the number of holes desired to be

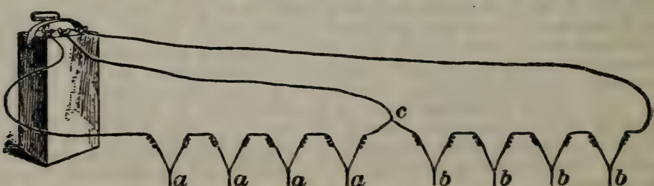


FIG. 5.

fired at one time; depth and spacing of holes depending on character of rock, size of drill holes, etc., the blaster, of course, using his judgment in this matter. Load the hole in the usual manner, fitting one cartridge with a fuse

(electric exploder) instead of cap and fuse. The fuse head is fitted into the bottom end of the cartridge, or into the middle of one side of the cartridge, where a hole has been punched with a pencil or small sharp stick to receive it; push the powder close around the fuse head. The fuse can then be held in position by tying a string around the cartridge and the fuse wires, binding the wires to the cartridge, as shown in Fig. 3. *A* shows head of fuse, *B* the two fuse wires, *C* string used to tie wires to cartridge. Avoid taking hitches in fuse wires, as by this very common practice, the insulation of the wires may be injured and the current of electricity may pass from one wire to the other, without passing through the cap, hazarding a misfire.

The cartridge containing the fuse is put in on top of the charge by some blasters; by others, at bottom of the charge. The best place for it is in the center of the charge, having part of the charge above and part below it. In tamping the hole, great care must be taken not to cut the wires, or injure the cotton covering of fuse wires, or to pull the fuse out of the cartridge. Allow at least 8 in. of the fuse wire to project above the hole, to make connections.

When all the holes to be fired at one time are tamped, separate the ends of the two wires in each hole, and, by the use of connecting wire, join one wire of the first hole with one of the second, the other or free wire of the second with one of the third, and so on to the last hole, leaving a free wire at each end hole.

All connections of wires should be made by twisting together the bare and clean ends; it is best to have the joined parts bright. Scrape off the cotton

FIG. 6.

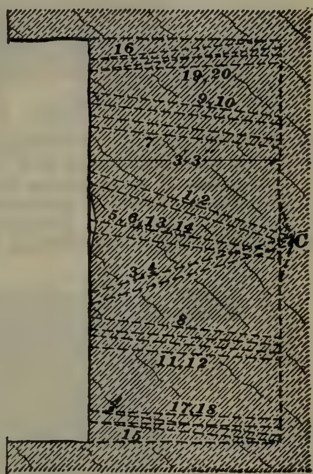


FIG. 7.

covering at the ends of the wires to be connected, say for 2 in., then rub the wire with a small hard stone. This makes a bright fresh wire. Be sure that all connections are clean, bright, and well twisted. Do not hook or loop wires in making connections. Bare joints in wire should never be allowed to touch the ground, particularly so if the ground is wet. This can be prevented by putting dry stones under the joints. The charges having all been connected, as directed above, the free wire of the first hole should be joined to one of the leading wires, and the free wire of the last hole to the other of the two leading wires. The leading wires should be long enough to reach a point at a safe distance from the blast, say 250 ft. at least. All being ready, and not till the men are at a safe distance, connect the leading wires, one to each of the projecting screws on the front side or top of the battery, through each of which a hole is bored for the purpose, and bring the nuts down firmly on the wires. Now, to fire, take hold of the handle for the purpose, lift the rack bar (or square rod, toothed on one side) to its full length, and press it down, for the first inch of its stroke with moderate speed, but finishing the stroke with all force, bringing rack bar to the bottom of the box with a solid **thud**, and the blast will be made. Do not churn rack bar up and down. It

is unnecessary and harmful to the machine. One quick stroke of the rack bar is sufficient to make the blast. Never use fuses (exploders) made by different manufacturers in the same blast. Connecting wire should be of

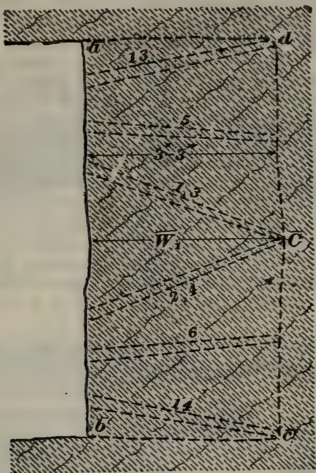


FIG. 8.

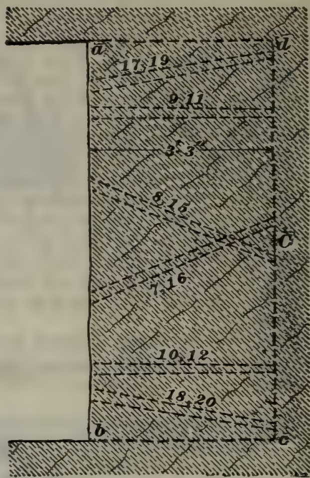


FIG. 9.

same size as the fuse wire; leading wire should be at least twice as large. Covering on wire should not "strip" or come off easily.

The **power of an explosive** cannot be exactly calculated from the quantity and temperature of the gas resulting from its detonation, as it is impossible to determine the exact composition of gas at the moment of explosion and during the subsequent cooling period. Tables that give the relative strength

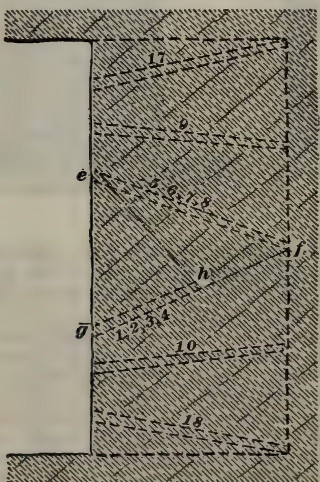


FIG. 10.

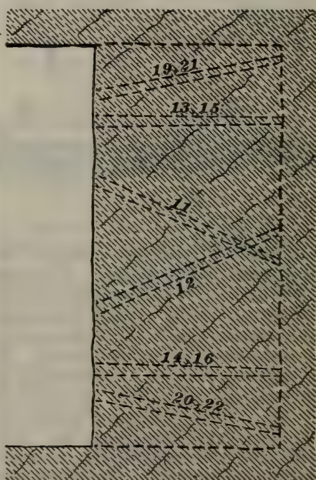


FIG. 11.

of explosives are apt to be misleading, as so much depends on the composition of the explosive, and since there are so many explosives of varying compositions that are sold under the same name.

Pressures Developed by Explosives.—According to experiments conducted

by Sarrau, Vielle, Noule, and Abel, the following approximate maximum pressures, in tons per square inch, developed by various explosives, have been arrived at: Mercury fulminate, 193; nitroglycerine, 86; guncotton, 71; blasting powder, 43.

Values of Explosives.—Taking gunpowder (containing 61% saltpeter) as a standard, and calling its value 1, the following are the comparative values

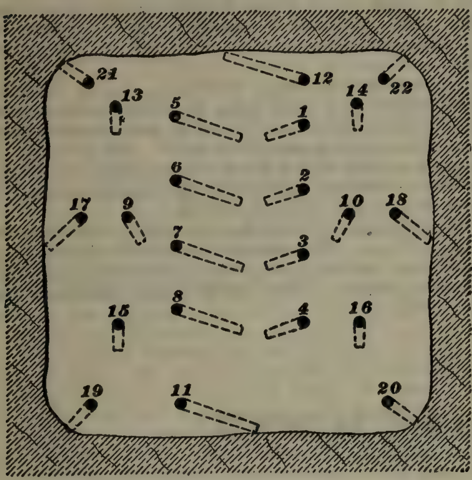


FIG. 12.

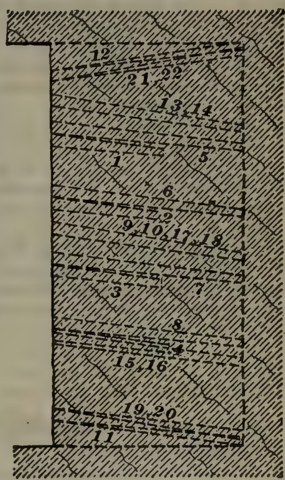


FIG. 13.

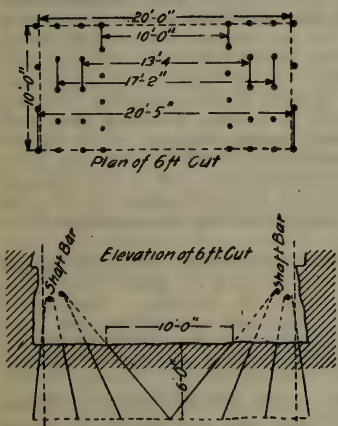


FIG. 14.

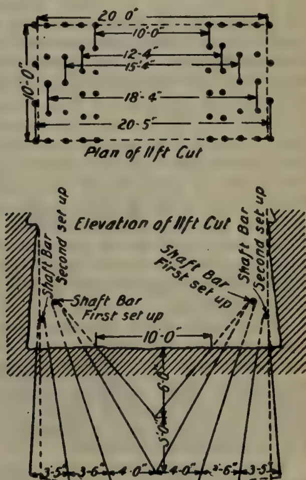


FIG. 15.

of the other explosives: Dynamite, containing 75% nitroglycerine, 2.2; blasting gelatine, containing 92% nitroglycerine, 3.2; nitroglycerine, 3.3.

The **arrangement of drill holes** for driving and sinking should be such as to permit the easy handling of the drills and also to minimize the number of holes and the weight of explosive. Two distinct systems are in use: (1) the *center cut*, by which a center core or key is first removed, and after that concentric layers about this core; (2) the *square cut*, in which the lines of

holes are parallel to the sides of the excavation, the rock being removed in wedges instead of in concentric circles.

The center-cut method is shown in Figs. 6, 7, 8, and 9, Fig. 6 showing the face of a heading, Fig. 7 an elevation or vertical section, and Figs. 8 and 9 plans. The numbers of the holes correspond in the several views. The holes are supposed to be drilled by rock drills, and they are so placed that all except the *breaking-in* holes have an equal line of resistance. The number of holes given is supposed to take out a clean cut of the whole section *a b c d* to the extent of 3 ft. 6 in. The order of firing the holes is: (1) breaking-in shots *1, 2, 3,* and *4* simultaneously; (2) *5, 6, 7, 8*; (3) *9, 10, 11, 12*; (4) *13, 14, 15, 16*; (5) *17, 18, 19, 20*.

The square-cut arrangement is shown in Figs. 12 (face), 10, 11 (plans), and 13 (vertical elevation). The entering wedge, Fig. 11, is best removed in two stages: First, the part *e g h* by the shots *1, 2, 3,* and *4*; and second, part *e f h* by shots *5, 6, 7,* and *8*. The other shots are then fired: (1) *9, 10, 11, 12*: (2) *13, 14, 15, 16*; (3) *17, 18, 19, 20*, each volley being fired either simultaneously or consecutively. Where there is a natural parting in the heading, advantage is, of course, taken of this in the location of the shots.

Figs. 14 and 15 show two arrangements of drill holes used in sinking the Parker shaft at Franklin Furnace, N. J. The size of the shaft was 10 ft. × 20 ft. in the rock. At first, only 6′ cuts were put in, but these were gradually increased until 11′ and 12′ cuts were pulled. The best average obtained was 66 ft. of shaft from 6 consecutive cuts.

MACHINE MINING.

The number of coal-mining machines in use has increased rapidly within a very short time. In 1896 there were 1,446 in use in the United States. During 1897 there was an increase of 542, or 37.5%, while the average yearly gain from 1891 to 1896 was only about 22%. The total tonnage won by machines in 20 States in 1897 was 22,649,220 short tons, or 16.17% of the total product of these States, and 15.3% of the total bituminous product of the United States. A universal mining machine has not yet been brought out, and one of the principal reasons for the failure of mining machines in a number of instances has been the attempt to use a machine under conditions to which it was not adapted. When a mining machine is designed and built to suit the conditions under which it is to be operated, it is safe to say that there are but few mines in which they cannot be successfully utilized. They are of particular advantage where there is a long working face and where the coal is over 3 ft. in thickness. Low seams require more undercutting for the given output than high seams. As a rule it has not been found economical to use machines in seams pitching over 12° to 15°, though pick machines have been used in mines having an inclination of 23°, the difficulty being not so much in the cutting as in moving the machine from place to place.

There are four general types of mining machines in use; pick machines, chain-cutter machines, cutter-bar machines, and longwall machines. The first two are the types almost universally used in America. Cutter-bar machines have almost entirely disappeared from use excepting one type which is at present used in Iowa. Longwall mining machines have not been very generally adopted in America, as the longwall method of mining is not extensively used.

Both compressed air and electricity are used for operating mining machines. Pick machines driven by compressed air are made by three separate concerns. Four companies make electric chain machines and one of these four is also making a compressed-air chain machine. One makes a longwall machine, and one has brought out a pick machine for electric power.

Pick machines work very similarly to a rock drill. They can be used wherever mining machines are applicable, and their particular advantage is that they are more perfectly under the control of the operator, who can cut around pyrites and similar obstructions without cutting them with the machine. This renders such a machine particularly applicable for seams of

coal having rolls in the bottom and containing pyrites or other hard impurities. They are also applicable for working pillars on which there is a squeeze, as they are light and can be easily handled and readily removed.

Chain-cutter machines consist of a low metal bed frame upon which is mounted a motor that rotates a chain to which suitable cutting teeth are attached. To operate chain machines to the best advantage, the coal should be comparatively free from pyrites. They also require more room than pick machines, and a space from 12 to 15 ft. in width is necessary along the face to work them to advantage. These machines have proved failures in some mines on account of the incessant jarring of the roof by the rear jack. Chain-cutter machines cannot be used to undercut coal when a squeeze is upon it. Coal seams that are comparatively level and free from pyrites and have a comparatively good roof can undoubtedly be more satisfactorily and economically cut with chain-cutter machines than with any other type.

The average height of cut is 4½ to 5 in., and at this height, the chain-cutter machines makes only about 60% as much small coal as a pick machine. This is not always an advantage, as it does not always allow sufficient height for the coal to fall down after the cut is made. In a 3½′ seam, 3 men are required to handle the machine to advantage.

Shearing.—All the pick machines can be converted into shearing machines and can be used for longwall work by using a longer striking arm and a longer supply hose. The chain machines are used to do shearing work by having the cutting parts turned vertically.

Capacity.—The average producing capacity of each mining machine used in the United States was 11,398 tons in 1891, 11,373 tons in 1896, and 11,393 tons in 1897. So much depends on the local conditions that it is almost impossible to give specific data of rates of working and costs, but the following are fair working approximations.

A good pick machine will undercut 450 sq. ft. in 10 hours, while an ordinary miner will undercut 120 sq. ft. in the same time. In a seam varying from 4½ to 6 ft. in thickness, the machine will undercut from 50 to 100 tons of coal in 10 hours. The cost of undercutting under these conditions has been given as approximately 10 cents per ton. Extraordinary records show 1,400 sq. ft. to have been cut in 9 hours in Western Pennsylvania, and in an 8′ seam, 240 tons have been undercut in a shift of 10 hours.

A good chain cutter will make from 30 to 45 cuts, 44 in. wide and 6 ft. deep, in 10 hours under moderately fair conditions, while in high seams two men handling the same machine under ordinary conditions can make 60 cuts per shift, and under particularly favorable conditions, 80 to 120 cuts per shift.

VENTILATION OF MINES.

This subject is divided naturally into (*a*) gases occurring in workings, explosive conditions, quantity of air, distribution of air, and (*b*) ventilating methods and machinery.

THE ATMOSPHERE.

Composition.—Air consists chiefly of oxygen and nitrogen, with small and varying amounts of carbonic-acid gas, ammonia gas, and aqueous vapor. These gases are not chemically combined, but exist in a free state in uniform proportion, as follows:

	By Volume.	By Weight.
Nitrogen	79.3	77.0
Oxygen	20.7	23.0
	100.0	100.0

Wherever air is found, its composition is practically the same.

Weight.—The weight of 1 cu. ft. of air at 32° F. and under a barometric pressure of 30 in. is .080975 lb. Air decreases in weight per cubic foot as we ascend in the atmosphere, and increases as we descend below the surface of the earth.

The weight of 1 cu. ft. of dry air at any temperature and barometric pressure is found by means of the formula

$$w = \frac{1.3253 \times B}{459 + t},$$

in which w = weight of 1 cu. ft. of dry air; B = barometric pressure (inches of mercury); t = temperature (degrees F.).

The constant 1.3253 is the weight in pounds avoirdupois of 459 cu. ft. of dry air at a temperature of 1° F. and 1 in. barometric pressure.

EXAMPLE.—Find the weight of 1 cu. ft. of dry air at a temperature of 60° F. and a barometric pressure of 30 in.

$$w = \frac{1.3253 \times 30}{459 + 60} = .0766 \text{ lb.}$$

TABLE OF WEIGHT OF DRY AIR.

Weight of 1 cu. ft. of dry air at different temperatures and barometric pressures, as calculated by the formula $w = \frac{1.3253 \times B}{459 + t}$.

Temperature. Degrees F. t	Weight of 1 Cu. Ft. of Dry Air (Lb. Avoirdupois).			
	Barometer (In.). $B = 27$.	Barometer (In.). $B = 28$.	Barometer (In.). $B = 29$.	Barometer (In.). $B = 30$.
0	.07796	.08085	.08373	.08662
5	.07718	.08002	.08285	.08569
10	.07631	.07914	.08196	.08478
15	.07550	.07830	.08109	.08388
20	.07470	.07747	.08023	.08300
25	.07393	.07667	.07941	.08215
30	.07318	.07589	.07860	.08131
32	.07288	.07558	.07828	.08098
35	.07244	.07512	.07780	.08048
40	.07171	.07435	.07701	.07967
45	.07099	.07362	.07625	.07888
50	.07031	.07291	.07551	.07811
55	.06961	.07219	.07477	.07735
60	.06895	.07150	.07405	.07660
65	.06828	.07081	.07324	.07587
70	.06766	.07016	.07266	.07516
75	.06701	.06949	.07197	.07445
80	.06648	.06884	.07130	.07376
85	.06576	.06820	.07064	.07308
90	.06519	.06760	.07001	.07242
95	.06490	.06699	.06938	.07177
100	.06401	.06638	.06875	.07112
110	.06288	.06521	.06754	.06987
120	.06180	.06409	.06638	.06867
130	.06075	.06300	.06525	.06750
140	.05974	.06195	.06416	.06637
150	.05874	.06092	.06310	.06528
160	.05781	.05995	.06209	.06423
170	.05688	.05899	.06110	.06321
180	.05601	.05808	.06015	.06222
190	.05514	.05718	.05922	.06126
200	.05430	.05631	.05832	.06033
220	.05271	.05466	.05661	.05856
240	.05119	.05309	.05498	.05688
260	.04978	.05162	.05346	.05530
280	.04840	.05020	.05200	.05380
300	.04714	.04888	.05063	.05238
350	.04423	.04587	.04751	.04915
400	.04166	.04321	.04475	.04629

Atmospheric Pressure.—The term *barometric pressure* is the pressure caused by the weight of the atmosphere above a given point. It is measured by the barometer, and this gives rise to the synonymous term *barometric pressure.* Atmospheric pressure is usually stated in pounds per square inch, while barometric pressure is stated in inches of mercury. Thus, at sea level, the atmospheric pressure under normal conditions of the atmosphere is 14.7 lb. per sq. in., while the barometric pressure at the same level is 30 in. of mercury column, or simply 30 in.

Barometric Variations.—The pressure of the atmosphere is not constant, but is subject to fluctuations depending on the condition of the atmosphere. Besides these, there are fluctuations that are more or less regular and are called *barometric variations.* There is both a yearly and a diurnal, or daily, variation. Of these two, the more important and the more regular is the daily variation, in which the barometer attains a maximum height from 9 to 10 o'clock A. M., and a minimum about 4 o'clock P. M. Other maximum and minimum readings are obtained at 10 P. M. and 3 A. M., respectively; but these are not as pronounced as those occurring in the daytime. The daily barometric variations range from .01 to .08 in.

Mercurial Barometer.—This barometer is often called the *cistern barometer;* or, when the lower end of the tube is bent upwards instead of the mouth of the tube being submerged in a basin, it is known as the *siphon barometer.* The instrument is constructed by filling a glass tube 3 ft. long, and having a bore of ¼ in. diameter, with mercury, which is boiled to drive off the air. The thumb is now placed tightly over the open end, the tube inverted, and its mouth submerged in a basin of mercury. When the thumb is withdrawn, the mercury sinks in the tube, flowing out into the basin, until the top of the mercury column is about 30 in. above the surface of the mercury in the basin, and after a few oscillations above and below this point, comes to rest. The vacuum thus left in the tube above the mercury column is as perfect a vacuum as it is possible to form, and is called a *Torricelli vacuum*, after its discoverer. There being evidently no pressure in the tube above the mercury column, and as the weight of this column standing above the surface of the mercury in the basin is supported by the pressure of the atmosphere, it is the exact measure of the pressure of the atmosphere on the surface of the mercury in the basin. If the experiment is performed at sea level, the height of the mercury will be found to average about 30 in., at higher elevations it is less, while if we descend deep shafts below this level, it is greater. Roughly speaking, an allowance of 1 in. of barometric height is made for each 900 ft. of ascent or descent from sea level (see calculation of barometric elevations). A thermometer is attached to each mercurial barometer to note the temperature of the reading, as it is customary in all accurate work with this instrument to reduce each reading to an equivalent reading at 32° F., which is the standard temperature for barometric readings. A scale is provided at the top of the mercury column with its inches so marked upon it as to make due allowance for what is called the *error of capacity.* In other words, the inches of the scale are longer than real inches, since the level of the mercury in the basin rises as it sinks in the tube, and vice versa. The top of the mercury column is always oval, convex upwards, owing to capillary attraction, and the scale is read where it is tangent to this convex surface.

Aneroid Barometer.—This is a more portable form than the mercurial barometer. It consists of a brass box resembling a steam-pressure gauge, having a similar dial and pointer, the dial, however, being graduated to read inches, corresponding to inches of mercury column, instead of reading pounds, as in a pressure gauge. Within the outer case is a delicate brass box having its upper and lower sides corrugated, which causes it to act as a bellows, moving in and out as the atmospheric pressure on it changes. The air within the box has been partially exhausted, to render it sensitive to atmospheric changes. The movement of the upper surface of the box is communicated to the pointer by a series of levers, and the dial is graduated to correspond with the mercurial barometer.

Calculation of Atmospheric Pressure.—The weight of the mercury column of the barometer is the exact measure of the pressure of the atmosphere, since it is the downward pressure of the atmosphere that supports the mercury column, *area for area;* that is to say, the pressure of the atmosphere on 1 sq. in. supports a column of mercury whose area is 1 sq. in., and whose height is such that the weight of the mercury column is equal to the weight of the atmospheric column. Hence, since 1 cu. in. of mercury weighs .49 lb.,

the atmospheric pressure that supports 30 in. of mercury column is $.49 \times 30 = 14.7$ lb. per sq. in. In like manner, the atmospheric pressure corresponding to any height of mercury column may be calculated. It will be observed that the sectional size of the mercury column is not important, since it is supported by the atmospheric pressure on an equal area, but the calculation of pressure is based on 1 sq. in.

Water Column Corresponding to Any Mercury Column.—The density of mercury referred to water is practically 13.6; hence, the height of a water column corresponding to a given mercury column is 13.6 times the height of the mercury column. For example, at sea level, where the average barometric pressure is 30 in. of mercury, the height of water column that the atmospheric pressure will support is $13.6 \times \frac{30}{12} = 34$ ft. This is the theoretical height to which it is possible to raise water by means of a suction pump, but the length of the suction pipe should not exceed 75% or 80% of the theoretical water column.

Calculation of Barometric Elevations.—Such elevations, although approximate, are useful for many purposes. The barometric readings are reduced to equivalent readings at the standard temperature of 32° F., and for determining differences in elevation, the readings of two barometers should be taken, if possible, at the same time. It must not be supposed, however, that the barometer always reads the same for the same elevation at this temperature. The temperature of the atmosphere has indeed very little effect on the atmospheric pressure, which is due to the weight of air above the point of observation, aerial currents, and other phenomena.

In the more accurate determinations of vertical height or elevation by means of the barometer, the following formula is usually employed:

R = reading of barometer (inches) at lower station;
r = reading of barometer (inches) at higher station;
T = temperature (F.) at lower station;
t = temperature (F.) at higher station;
H = difference of level in feet between the two stations.

$$H = 56{,}300(\log R - \log r)\left(1 + \frac{T+t}{900}\right).$$

$$\therefore \log R = \frac{H}{56{,}300\left(1 + \frac{T+t}{900}\right)} + \log r.$$

More simply:
$$H = 49{,}000\left(\frac{R-r}{R+r}\right)\left(1 + \frac{T+t}{900}\right).$$

$$\therefore R = r\left[\frac{49{,}000(900 + T + t) + 900H}{49{,}000(900 + T + t) - 900H}\right].$$

Correction for Temperature.—Mercury expands about .0001 of its volume for each degree Fahrenheit. To reduce, therefore, a reading at any temperature to the corresponding reading at the standard temperature of 32° F., subtract $\frac{1}{10000}$ of the observed height for each degree above 32°; or, if the temperature is below 32°, add $\frac{1}{10000}$ for each degree.

Thus, 30.667 in. at 62° F. is equivalent to a reading of 30.555 in. at 32° F., since $30.667 - \frac{62-32}{10{,}000}(30.667) = 30.667 - .092 = 30.555$ in.

Depth of Shafts.—The barometer is often employed to determine the depth of a shaft or the depth of any point in a mine below a corresponding point on the surface. The aneroid is employed for this work, being more portable. Allowance must always be made in such cases for the ventilating pressure of the mine. A simple formula often used for such calculations is the following:

$$H = 55{,}000\left(1 - \sqrt{\frac{r}{R}}\right),$$

in which the letters stand for the same factors as designated above.

The most important use of the barometer in mining practice, however, is found in the warning that it gives of the decrease of atmospheric pressure, and the expansion of mine gases that always follows.

CHEMISTRY OF GASES.

All matter exists in one of three forms, *solid*, *liquid*, or *gaseous*, according to the predominance of the attractive or the repulsive forces existing between the molecules. For example, water exists as ice, or in a solid form, when the attractive force exceeds the repulsive force between its molecules. As the temperature is raised or heat is applied, the ice assumes the liquid form due to the more rapid vibration of the molecules of which it is composed. In other words, the repulsive force existing between the molecules is increased, and the result is a liquid. If we still further raise the temperature by applying more heat, the vibration of the molecules becomes yet more rapid, the repulsive force is increased between the molecules, and a gas or vapor called steam is formed.

An *atom* is the smallest conceivable division of matter.

A *molecule* is a collection of two or more atoms, united by affinity.

The atom cannot consist of more than one element. The molecule may be either simple or compound. If compound, it is a chemical compound, its atoms being chemically united.

Chemical Compounds.—A chemical compound is one formed by the union of two or more atoms chemically, such atoms uniting always in fixed or definite proportions. The properties of a chemical compound are always the same.

Mechanical Mixture.—A mechanical mixture is composed of different substances that are not chemically united, and which are mixed in no fixed proportion. The properties of a mechanical mixture present a regular gradation from a maximum to a minimum state. Thus, a solution of common salt $NaCl$ in water is not a chemical compound of salt and water, but simply a mechanical mixture of the salt in the water. If more salt is added to the water, the strength of the mixture or the brine is increased; and when less salt is present, the strength is less. On the other hand, salt itself is a chemical compound formed by the union of 1 atom of sodium with 1 atom of chlorine, the two atoms being bound together by chemical affinity, and always uniting in the same proportion, 1 atom of each, to form salt.

The air that we breathe is a mechanical mixture of nitrogen and oxygen gases, with small amounts of other ingredients. The nitrogen and oxygen gases are in a free state; that is to say, they are not combined as in a chemical compound. This is true, although the proportion of these two gases, oxygen and nitrogen, in the atmosphere, is uniformly in the ratio of, say, 1 volume of oxygen to 4 of nitrogen. Firedamp is another example of true mechanical mixture, consisting chiefly of a mixture of marsh gas CH_4 and air, with small amounts of other hydrocarbons and a varying amount of carbonic-acid gas, which is always present in firedamp. These gases are not combined chemically, but are mixed in varying proportions.

Atomic volume, or *specific volume*, means simply *relative volume*. These terms refer to the relative volume of gases resulting from any particular reaction. By means of the laws of atomic volume, we can ascertain the volumes of the different gases resulting from any particular reaction. The chemical reaction that takes place between the elements constituting the different gases is expressed by means of a chemical equation. When we have expressed such reaction by a chemical equation, we can then calculate the volumes of the gases formed, with respect to the original volumes of the gases entering into the reaction. It must be observed, however, that the atomic volumes express merely the *relative* volumes of gases; or, in other words, the ratio of the volumes of gases before and after the reaction takes place.

Laws of Volume.—The following laws of volume refer to gases only, and never to solids or liquids:

First.—Equal volumes of all gases, under the same conditions of temperature and pressure, contain the same number of molecules. Hence, the molecules of all simple gases are of the same size.

Second.—The molecules of compound gases, under like conditions of temperature and pressure, occupy twice the volume of an atom of hydrogen gas.

There are very few exceptions to these two laws of gaseous volume, and the exceptions are unimportant so far as mining practice is concerned.

An element is a form of matter that is composed wholly of like atoms. Thus, hydrogen, oxygen, iron, copper, gold, and silver are elements.

Chemical Symbols and Equations.—To facilitate the writing of chemical

equations expressing the reaction that takes place between elements under certain conditions, it is usual to express the elements by letters called *symbols*. These symbols stand for the elements that they represent, and are written as capital letters, except where two letters are used to express a symbol, in which case the first letter only is a capital. Thus, *C* is the symbol for the element carbon, but *Cu* is the symbol for copper (cuprum) and *Co* is the symbol for cobalt. It is important that these symbols be written exactly in this manner; otherwise they are liable to be frequently misconstrued. For example, *Co* stands for cobalt, while the symbol *CO*

TABLE OF ELEMENTS.

Element.	Symbol.	Atomic Weight.	Element.	Symbol.	Atomic Weight.
Aluminum	*Al*	27.5	Manganese	*Mn*	55.0
Antimony (stibium)	*Sb*	120.0	Molybdenum	*Mo*	96.0
Argon(?)	*A*		Neodymium(?)	*Nd*	
Arsenic	*As*	75.0	Nickel	*Ni*	58.8
Barium	*Ba*	137.0	Niobium	*Nb*	94.0
Beryllium	*Be*	9.4	Nitrogen	*N*	14.0
Bismuth	*Bi*	208.0	Osmium	*Os*	191.0
Boron	*B*	11.0	Oxygen	*O*	16.0
Bromine	*Br*	80.0	Palladium	*Pd*	106.5
Cadmium	*Cd*	112.0	Phosphorus	*P*	31.0
Cæsium	*Cs*	133.0	Platinum	*Pt*	197.0
Calcium	*Ca*	40.0	Potassium (kalium)	*K*	39.0
Carbon	*C*	12.0	Praseodymium(?)	*Pr*	
Cerium	*Ce*	138.0	Rhodium	*Rh*	104.0
Chlorine	*Cl*	35.5	Rubidium	*Rb*	85.0
Chromium	*Cr*	52.5	Ruthenium	*Ru*	104.0
Cobalt	*Co*	59.0	Samarium(?)	*Sa*	
Columbium	*Cb*	93.7	Scandium	*Sc*	
Copper (cuprum)	*Cu*	63.0	Selenium	*Se*	79.0
Didymium	*D*	147.0	Silicon	*Si*	28.0
Erbium(?)	*Er*	169.0	Silver (argentum)	*Ag*	108.0
Fluorine	*F*	19.0	Sodium (natrium)	*Na*	23.0
Gallium	*Ga*	69.0	Strontium	*Sr*	87.5
Germanium	*Ge*		Sulphur	*S*	32.0
Gold (aurum)	*Au*	196.7	Tantalum	*Ta*	182.0
Helium(?)	*He*		Tellurium	*Te*	127.0
Hydrogen	*H*	1.0	Thallium	*Tl*	205.0
Indium	*In*	113.4	Thorium	*Th*	231.5
Iodine	*I*	127.0	Tin (stannum)	*Sn*	108.0
Iridium	*Ir*	193.0	Titanium	*Ti*	48.0
Iron (ferrum)	*Fe*	56.0	Tungsten (wolfram)	*W*	184.0
Lanthanum	*La*	139.0	Uranium	*U*	240.0
Lead (plumbum)	*Pb*	207.0	Vanadium	*V*	51.2
Lithium	*Li*	7.0	Ytterbium	*Yb*	
Magnesium	*Mg*	24.0	Yttrium	*Y*	89.0
			Zinc	*Zn*	65.0
Mercury (hydrargyrum)	*Hg*	200.0	Zirconium	*Zr*	90.0

stands for carbonic-oxide gas, which is a chemical compound composed of two elements, carbon and oxygen.

A molecule is expressed by writing the symbols of its elementary atoms. Where more than 1 atom of a substance or element enters into the composition of a molecule, the number of atoms of such element is expressed by a small subscript letter written immediately after the symbol of the element. Thus, carbonic-acid gas is composed of 1 atom of carbon chemically united with 2 atoms of oxygen, and is expressed by the symbol CO_2. Where the symbol is written without such subscript figure, 1 atom only is meant. Thus, carbonic-oxide gas being composed of 1 atom of carbon chemically united to 1 atom of oxygen, is expressed by the symbol *CO*.

A large figure written before the symbols expressing the molecule indicates the number of molecules entering into the reaction. A large figure is sometimes used before the symbol of a single element to indicate the number of atoms of that element that enter the reaction. In any reaction occurring between atoms of matter, no matter is destroyed. In any reaction, there are always the same number of atoms after the reaction as before the reaction took place. A chemical equation is therefore an expression of equality between the atoms before and after a reaction takes place. The first member of the equation contains the substances that act upon each other, while the second member of the equation contains the substances that are formed by the reaction. The number of atoms is the same in each member of the equation.

EXAMPLE.—To express the reaction that takes place when carbonic-oxide gas burns in the air to produce carbonic-acid gas, we write

$$CO + O + 4N = CO_2 + 4N$$

In this equation, each molecule of carbonic-oxide gas CO takes up 1 atom of the free oxygen of the atmosphere to form carbonic-acid gas CO_2. The nitrogen in the atmosphere being 4 times the volume of oxygen, is expressed as 4 atoms in the equation. This nitrogen, however, remains inactive, and takes no part in the reaction. It is written on both sides of the equation for the purpose of determining the atomic volumes of the gases before and after the reaction, as explained below.

The reaction for an explosion of firedamp is

$$CH_4 + 4O + 16N = CO_2 + 2H_2O + 16N$$

In this equation, each molecule of marsh gas CH_4 is dissociated; that is to say, its atoms are separated. The atom of carbon in the molecule unites with 2 atoms of the oxygen of the air to form carbonic-acid gas CO_2. The 4 atoms of hydrogen, in like manner, combine with two atoms of oxygen in the air to form 2 molecules of water or steam $2(H_2O)$, or $2H_2O$. The nitrogen in this equation is equal to 4 times the volume of the oxygen consumed, and is therefore written as $16N$, since a total of 4 atoms of oxygen have been used. The nitrogen is however inert, and plays no part in the reaction itself, but is written here on both sides of the equation, as in the previous equation, in order to properly represent the atomic volumes of the gases or their relative volumes before and after the reaction takes place.

Calculation of the Relative Volumes of Gases.—To calculate the relative volumes of the gases before and after the reactions expressed in each of the equations given in the preceding paragraphs, write beneath the symbol of each molecule or atom its atomic volume. In the chemical equation expressing the reaction that takes place when carbonic-oxide gas CO burns to carbonic-acid gas CO_2, we have as follows:

$$\begin{array}{lc} & CO + O + 4N = CO_2 + 4N \\ \text{Atomic volumes,} & 2 + 1 + 4 = 2 + 4 \end{array}$$

or, in this reaction, 7 volumes have been reduced to 6 volumes. Such a change of volume often takes place in chemical reactions. All attempts to explain the cause of this change of volume, however, have thus far failed; but that the change of volume does take place has been demonstrated by a large number of experiments.

To calculate the volume of air consumed in the complete explosion of 100 cu. ft. of carbonic-oxide gas CO, we write the ratio of the relative volumes of carbonic-oxide gas and air, which is $2 : (1 + 4)$, or $2 : 5$; and to obtain the actual volume of air consumed in the explosion of 100 cu. ft. of carbonic-oxide gas, we write the proportion $2 : 5 :: 100 : x$, or $x = \frac{5 \times 100}{2} = 250$ cu. ft.

To find the volume of carbonic-acid gas CO_2 produced in the complete explosion of 100 cu. ft. of carbonic-oxide gas CO, write the ratio of the atomic volumes of these two gases $2 : 2$, which shows no change of volume, and, therefore, the volume of carbonic-acid gas CO_2 produced will be the same as the volume of carbonic-oxide gas CO burned.

To find the volume of air consumed in the complete explosion of 100 cu. ft. of marsh gas CH_4, write the equation expressing the reaction that takes place in this explosion as given above,

$$\begin{array}{lc} & CH_4 + 4O + 16N = CO_2 + 2H_2O + 16N \\ \text{Atomic volumes,} & 2 + 4 + 16 = 2 + 4 + 16 \end{array}$$

There is no change of volume caused by the explosion, since 22 volumes on one side of the equation produce, likewise, 22 volumes on the other side; or 22 volumes before the explosion produce 22 volumes after the explosion.

To find the volume of air consumed, we write the ratio of the atomic volumes of marsh gas and air 2 : (4 + 16), or 2 : 20, or 1 : 10; that is to say, roughly speaking, the amount of air consumed in the complete explosion of marsh gas is 10 times the volume of the marsh gas. This is not exact, however, as the volume of nitrogen in the air is 3.83 times the volume of oxygen. Making this correction, the volume of air consumed in the complete explosion of marsh gas is 9.66 times the volume of the gas.

To determine the percentage of pure marsh gas in the above firedamp mixture (marsh gas and air), we write the ratio of the atomic volumes of these two, 2 : (2 + 4 + 15.32), or 1 : 10.66; and $\frac{1}{10.66} \times 100 = 9.38\%$ of CH_4.

The volume of carbonic-acid gas formed in this reaction is equal to the volume of marsh gas consumed, and the volume of watery vapor is double the volume of marsh gas consumed; the total volume of gas and vapor formed by the reaction is the same as the original volume of marsh gas and air, or firedamp mixture, since the sum of the atomic volumes on each side of the equation is the same.

Atomic weight is the relative weight of an atom of an element compared with an atom of hydrogen. Atomic weight is, then, not an absolute weight to be expressed in pounds, ounces, or any other denomination, but is simply *relative* weight. The atomic weight of each of the elements is given in the table on page 342.

Molecular weight is the sum of the atomic weights of the elements forming the molecule, taking the atomic weight of each element as many times as there are atoms of that element in the molecule. A molecule of water is composed of 2 atoms of hydrogen and 1 atom of oxygen, and as the atomic weight of hydrogen is 1 and that of oxygen 16, the molecular weight of water is $(2 \times 1) + 16 = 18$. In the same manner, since a molecule of marsh gas CH_4 is composed of 4 atoms of hydrogen and 1 of carbon, and the atomic weight of hydrogen is 1 and that of carbon 12, the molecular weight of marsh gas is $(4 \times 1) + 12 = 16$.

The **density** of a gas is the weight of any volume compared with the weight of the same volume of hydrogen or some other standard. The density of a gas is constant at all temperatures and pressures, the change of temperature and pressure affecting the gas in question and the standard alike. The density of air referred to hydrogen is 14.38.

(*a*) *The density of any simple gas, referred to hydrogen as unity, is equal to its atomic weight.* (*b*) *The density of any compound gas, referred to hydrogen as unity, is one-half of its molecular weight.*

Specific Gravity of Gases.—The specific gravity of a gas is the weight of that gas referred to the weight of a like volume of air as a standard. It is, in other words, the ratio between the weight of like volumes of any gas and air, both the air and gas being subject to the same temperature and pressure. Thus, since the weight of 1 cu. ft. of air at a temperature of 60° F. and 30 in. barometric pressure is .0766 lb., and the weight of 1 cu. ft. of carbonic-acid gas CO_2 is .11712 lb. at the same temperature and pressure, the specific gravity of carbonic-acid gas is $\frac{.11712}{.0766} = 1.529$.

Weight of Gases.—The weight of 1 cu. ft. of any gas at any given temperature and pressure is found by first calculating the weight of 1 cu. ft. of dry air at the same temperature and pressure by means of the formula given on page 338 for air, and then multiplying this weight by the specific gravity of the gas referred to air as a standard.

EXAMPLE.—To determine the weight of 1 cu. ft. of carbonic-acid gas at a temperature of 60° F., and 30 in. barometric pressure, we multiply the weight of 1 cu. ft. of dry air, at this temperature and pressure, as found above (.0766 lb.), by the specific gravity of carbonic-acid gas (1.529). Thus, $.0766 \times 1.529 = .11712$ lb.

The table on page 349 gives the specific gravity of the gases common in mining practice, referred to air as a standard.

Expansion of Air and Gases.—All air and gases expand uniformly at the same rate. The expansion and contraction of air and gases follow two simple laws that we will consider under the heads (*a*) Ratio of volume and absolute temperature and (*b*) Ratio of volume and absolute pressure.

Absolute temperature means the temperature as reckoned from absolute zero, which is the point on the temperature scale below which it is assumed that no substance can exist in a gaseous state. The absolute zero of the

Fahrenheit scale is assumed in mining practice as 459° below zero. Hence, the absolute temperature corresponding to any common temperature is found by adding 459° to the common temperature. Thus, the absolute temperature corresponding to 60° F. is $459 + 60 = 519°$.

Absolute Pressure.—The term absolute pressure refers to the total pressure supported by air or gas; i. e., the pressure above a vacuum. *Gauge pressure* is the pressure above the atmosphere. Absolute pressure is always the atmospheric pressure plus the gauge pressure. If a gauge pressure on a boiler indicates 60 lb. per sq. in., the absolute pressure supported by the steam in the boiler will be $60 + 14.7 = 74.7$ lb. per sq. in. Or, if the ventilating pressure in a mine is equal to 13 lb. per sq. ft., the absolute pressure supported by the air in the airways will be $13 + (14.7 \times 144) = 2{,}129.8$ lb. per sq. ft.

Relation of Volume and Absolute Temperature (*Charles' or Gay Lussac's law*). *The volume of any air or gas varies directly as its absolute temperature.*

Relation of Volume and Absolute Pressure (*Boyle's or Mariotte's law*).—*The volume of any air or gas varies inversely as the absolute pressure it supports.* For example, if we double the absolute pressure supported by air or gas, the volume of the air or gas will be reduced to one-half its original volume; if we multiply the absolute pressure 3 times, we reduce the volume to one-third the original volume; etc.

EXAMPLE.—The intake current of a mine is 50,000 cu. ft. of air per minute; the ventilating pressure is 13 lb. per sq. ft. The temperature of the intake is 20° F.; the temperature of the return air is 70° F. Calculate the volume of the return air-current per minute, according to the rules of expansion of air, due to the increase of temperature and decrease of pressure, in the return current.

The increased volume of the return air, due to the decrease of pressure and increase of temperature, is found by writing a compound proportion, the first member of which consists of two ratios, viz., the direct ratio of the absolute temperatures, and the inverse ratio of the absolute pressures, according to the two laws stated above. That is, we write

$$\left.\begin{matrix}(459 + 20) & : & (459 + 70) \\ 2{,}116.8 & : & 2{,}129.8\end{matrix}\right\} :: 50{,}000 : x.$$

Or, $$x = \frac{529 \times 2{,}129.8 \times 50{,}000}{479 \times 2{,}116.8} = 55{,}558 \text{ cu. ft.}$$

EXAMPLE.—In a compressed-air plant, the gauge shows a pressure of 80 lb. per sq. in.; the area of the piston is 20 sq. in., and its stroke 10 in. The pump makes 100 strokes per minute. Assuming there is no leakage of air past the piston, what will be the volume of air discharged from the pump into the mine per minute?

The volume of air discharged from the pump cylinder per minute $= \frac{20 \times 10 \times 100}{1{,}728} = 11.57$ cu. ft. (cylinder pressure). The absolute pressure on the air in the cylinder is $80 + 14.7 = 94.7$ lb. The absolute pressure on the discharged air is simply the atmospheric pressure (14.7 lb.). Hence, we write the proportion $14.7 : 94.7 :: 11.57 : x$; or, $x = \frac{94.7}{14.7} \times 11.57 = 74.54$ cu. ft. per minute, nearly.

In calculating the expanded volume of air or gas, it will be observed that the ratio of the original volume to the expanded volume is always equal to the product of the direct ratio of the absolute temperatures and the inverse ratio of the absolute pressures, which gives a compound proportion, the first member of which consists of two ratios, the one a direct ratio and the other an inverse ratio.

Weight Produces Pressure.—In the study of the barometer as a means of measuring atmospheric pressure, we observe that the weight of the atmosphere produced the atmospheric pressure. In like manner, the weight of all fluids produces pressure, and this pressure acts equally in all directions. This is an important consideration in the study of mine ventilation, since it has given rise to the measurement of pressure by air or motive columns.

Calculation of Pressure.—An air column, or motive column, in ventilation, is a column of air having a base of 1 sq. ft., and of such height that its weight shall be equal to any given pressure. To calculate the height of air column corresponding to any given pressure, divide the pressure in pounds per square foot by the weight of 1 cu. ft. of the air. Mine pressure is also

measured by the water column that it will support, as in the water gauge, or by the mercury column, as in the barometer. In the measurement of pressure by means of the water column, the weight of the water column must be equal to the pressure, *area for area.*

Since the weights of these columns are proportional to their sectional areas, it makes no difference what this area may be, the weight of the column calculated for a sectional area of 1 sq. in. will equal the pressure per square inch that supports the same.

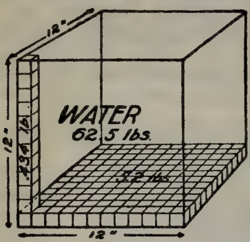


FIG. 1.

Hence, since 1 cu. in. of mercury weighs .49 lb., $.49 \times 30 = 14.7$ lb. is the atmospheric pressure corresponding to a height of 30 in. of mercury, or, as we say, 30 in. of barometer. If we consider a cubical box, as shown in the accompanying figure, holding exactly 1 cu. ft. of water, and assume the weight of the water to be 62.5 lb., as is usual in practice, and divide the bottom of the box into 144 sq. in., as shown in Fig. 1, we observe:

(*a*) The pressure of the water on the bottom of the box is equal to the weight of the water, 62.5 lb.; that is to say, *the pressure per square foot due to 1 ft. of water column is 62.5 lb.*

(*b*) The pressure on the bottom of the box, when the water is only 1 in. deep, is equal to the weight of a layer of water 1 in. thick, or $\frac{62.5}{12} = 5.2$ lb.; or, *the pressure per square foot due to 1 in. of water column is 5.2 lb.*

(*c*) The pressure per square inch on the bottom of the box is equal to the weight of a prism of water 1 ft. high, and having a base of 1 sq. in. $\frac{62.5}{144} = .434$; or, *the pressure per square inch due to 1 ft. of water column is .434 lb.*

These principles relating to the pressure of fluids are important to the student of mining, of which the following are examples:

1. In a mountainous country, several thousand feet above sea level, where the barometer registers, say, only 21 in., it is desired to know the theoretical height a pump will draw. $.49 \times 21 = 10.29$ lb. atmospheric pressure, and $\frac{10.29}{.434} = 24$ ft., nearly. The theoretical suction, in this instance, is 24 ft., nearly, but the actual draft or suction would vary from $\frac{2}{3}$ to $\frac{3}{4}$ of this, according to the perfection of the pump.

2. The water-gauge reading between the intake and return airways of a certain mine is 2.5 in.; to determine the pressure per square foot, we have, $2.5 \times 5.2 = 13$ lb. per sq. ft.

3. To determine the pressure per square foot on a mine dam, due to a vertical head of 200 ft., $62.5 \times 200 = 12{,}500$ lb.

4. To express in air column or motive column, a mine pressure equivalent to a water-gauge reading of 3 in., assuming the temperature of the air to be 60° F. and the barometric pressure 30 in., we have for the weight of 1 cu. ft. of air at this temperature and pressure $w = \frac{1.3253 \times 30}{459 + 60} = .0766$ lb. The pressure per square foot due to 3 in. of water gauge is $3 \times 5.2 = 15.6$. Then, we have for motive column, $m = \frac{15.6}{.0766} = 204$ ft.

Diffusion and Transpiration of Gases.—Diffusion of gases means the mixing of the gaseous volumes. Graham took several glass tubes, and inserting in one end of each a plug of plaster of Paris that was porous, he filled each tube with a different gas; as for example, oxygen, hydrogen, nitrogen, etc. He then placed the open end of each inverted tube in a basin of mercury, supporting the tubes in an erect position. The gas in each tube immediately began to diffuse through the porous plaster plug into the atmosphere, and it was observed that the mercury rose in each tube to take the place of the gas that passed into the atmosphere. The mercury rose in the hydrogen tube 4 times as fast as in the oxygen tube, and in the other tubes the mercury rose at different rates.

Rate of Diffusion (Graham's Law).—The rate of diffusion of gases into air is

in the *inverse* ratio of the square roots of their densities. The density of oxygen being 16 and hydrogen 1, the rate of diffusion of oxygen as compared with hydrogen is 1 to 4; that is to say, the rate of diffusion of oxygen is only one-fourth that of hydrogen.

TABLE SHOWING THE CORRESPONDING MERCURY AND AIR COLUMNS, AND PRESSURE PER SQUARE FOOT FOR EACH INCH OF WATER COLUMN.

Water Gauge. Inches.	Mercury Column. Inches.	Air Column. Feet (T. 60°, B. 30″).	Pressure. Lb. per Sq. Ft.	Water Gauge. Inches.	Mercury Column. Inches.	Air Column. Feet (T. 60°, B. 30″).	Pressure. Lb. per Sq. Ft.
1	.0735	68	5.2	6	.4412	407	31.2
2	.1471	136	10.4	7	.5147	475	36.4
3	.2206	204	15.6	8	.5882	543	41.6
4	.2941	272	20.8	9	.6618	611	46.8
5	.3676	340	26.0	10	.7353	679	52.0

TABLE SHOWING THE CORRESPONDING WATER COLUMN, AND PRESSURE PER SQUARE FOOT FOR EACH INCH OF MERCURY COLUMN.

Barometer. Inches.	Water Column. Feet.	Pressure. Lb. per Sq. In.	Barometer. Inches.	Water Column. Feet.	Pressure. Lb. per Sq. In.
1	1.13	.49	16	18.13	7.84
2	2.27	.98	17	19.27	8.33
3	3.40	1.47	18	20.40	8.82
4	4.54	1.96	19	21.53	9.31
5	5.67	2.45	20	22.67	9.80
6	6.80	2.94	21	23.80	10.29
7	7.93	3.43	22	24.93	10.78
8	9.06	3.92	23	26.07	11.27
9	10.20	4.41	24	27.20	11.76
10	11.33	4.90	25	28.33	12.25
11	12.46	5.39	26	29.47	12.74
12	13.60	5.88	27	30.60	13.23
13	14.73	6.37	28	31.73	13.72
14	15.87	6.86	29	32.87	14.21
15	17.00	7.35	30	34.00	14.70

NOTE.—One foot of water column is equivalent to a pressure of .434 lb. per sq. in. The weight of air at 60° F., barometer 30 in., is $\frac{1}{815}$ the weight of water; but the ratio of air to water is often assumed as 1.2 : 1,000, for quick calculation. The specific gravity of mercury at 32° F. (standard temperature for barometric readings) is 13.62; and a cubic foot of mercury at this temperature weighs 849 lb. For ordinary calculation, the weight of 1 cu. ft. of water is taken as 62.5 lb. The exact weight of 1 cu. ft. of pure water, at a temperature of 32° F., is, however, 62.418 lb.

The diffusion of marsh gas (Sp. Gr. .559) is much more rapid than that of carbonic-acid gas (Sp. Gr. 1.529). The diffusion of gases, however, is greatly assisted by the movement of the air-current; or by the movement of the gas as it tends to rise or fall, according to its relative density and position in the airway. For example, suppose a gas feeder to be located in the floor of an airway. The marsh gas given off from the feeder, being lighter than air,

tends to rise toward the roof. The action of rising helps a diffusion of this gas very much. On the other hand, a feeder located in the roof gives off the same gas, which tends to accumulate along the roof, and if the air-current is at all sluggish at this point, the diffusion of the marsh gas will be comparatively slow. It often happens that a feeder in the roof or other high point of the workings gives off gas more quickly than diffusion can take place, where the air-current is sluggish. This results in the accumulation of a body of pure marsh gas at this point. In like manner, we often have an accumulation of a large body of carbonic-acid gas, or blackdamp, near the floor or other low place in the mine workings, where the air-current is sluggish and where the blackdamp is formed quicker than diffusion takes place.

Limit of Diffusion.—The diffusion of gases continues to take place until the mixture of the gases is uniform. It is a curious fact that this takes place earlier or quicker in the case of gases whose densities differ widely, than where the densities of the two gases are nearly alike. Thus, saturation will take place more quickly in the diffusion of carbonic-acid gas into air than in the diffusion of firedamp into air, although the rate of diffusion of the latter is greater than of the former, firedamp being lighter than carbonic-acid gas.

The property of diffusion is of the greatest importance in the ventilation of mines, since it is owing to this that the air-current is enabled to sweep away these gases from their lurking places in the workings more rapidly and effectually than it otherwise could.

Transpiration of gases is the exuding of the gases from the pores of the coal in which they are contained. It is a well-known fact that transpiration takes place more rapidly from a newly exposed face of coal. This is owing to the fact that the gas pent up in the coal, or occluded in the seam, tends to escape at the first opportunity, when the seam is exposed to the atmosphere. The gas is under a certain pressure, as we have previously observed, and, as the mine workings penetrate the coal seam, the gases are forced outward from the coal by their own pressure, thus expanding into the air of the mine.

The transpiration of gas from coal seams differs very widely, in some seams it being so rapid and violent as to splinter and break the coal in its effort to escape. It frequently causes a crackling sound peculiar to a very gaseous seam, and in some cases, causes fine coal to be thrown into the face of the miner.

GASES FOUND IN MINES.

Oxygen O is a colorless, odorless, tasteless, non-poisonous gas. It is heavier than air, having a specific gravity of 1.1056. It is the great supporter of life and combustion. *Oxidation*, or the union of any of the elements with oxygen, is simply another term for *combustion* in its broadest sense. Most forms of matter containing carbon are easily decomposed at certain temperatures, through carbon seeking to combine with the oxygen of the air to form carbonic-acid gas CO_2. This union of the oxygen with other elements, or oxidation, takes place at all temperatures. It is less active when the temperature is low, and is then known as *slow combustion*. An example of this is found in the gob fires that occur so frequently in mine workings. The fine coal that is so often thrown back into the gob is acted on first by moisture, and as its temperature rises, carbonic-oxide gas is formed in small quantities by the union of the carbon of the coal with the oxygen of the air; as the temperature rises, more gas is formed. Heat is caused by the chemical action due to the interchange of the atoms, this heat being often sufficient to ignite the gas formed, spontaneous or active combustion resulting. Oxygen is the element in the atmosphere on which all life depends.

Nitrogen N is a colorless, odorless, and tasteless gas: it is neither combustible nor a supporter of combustion; it is not poisonous, and is lighter than air, having a specific gravity of .9713. Nitrogen is a particularly inert gas; it takes no active part in any combustion, in the sense of causing such combustion. Its province is to dilute oxygen of the atmosphere, on which life depends. Were it not for this dilution, oxidation would be too rapid, and not as completely under control as at present. The effect of nitrogen on human life would be to suffocate, if breathed pure, inasmuch as it would exclude oxygen from the lungs. Nitrogen itself has no life-giving power.

Marsh gas CH_4, often called *light carbureted hydrogen*, or *methane*, is a chemical compound, consisting of 4 atoms of hydrogen to 1 atom of carbon.

It is one of the chief gases occluded in coal seams, and results from the metamorphism of the carbonaceous matter from which coal is formed, when such metamorphism has taken place with the exclusion of air, and in presence of water. Pure marsh gas is colorless, odorless, and tasteless, and is lighter than air. Its specific gravity is .559, and it diffuses rapidly in the air, forming a firedamp mixture. Marsh gas burns with a blue flame, but it will not support combustion, and a lamp placed in it is immediately extinguished. In the mine, it is a difficult matter to place a lamp in a body of pure marsh gas, since the gas diffuses so rapidly that a firedamp mixture always surrounds a body of pure gas, which may exist high up in some cavity of the roof, or at the face of a steep pitch where the circulation is slow and the feeder at the face is giving off a large amount of gas. The flaming of the lamp in passing through a firedamp mixture would at once cause the withdrawal of the lamp before reaching the body of pure marsh gas. But could a lamp be placed in a body of pure marsh gas, it would be extinguished at once. Marsh gas is not poisonous, and when mixed with air in sufficient proportion, it may be breathed for a considerable time with impunity (see Firedamp). Pure marsh gas does not support life, but suffocates by excluding oxygen from the lungs.

Other Hydrocarbons.—All gases that are compounds of carbon and hydrogen are called *hydrocarbons*. Of these, the chief member is marsh gas, or light carbureted hydrogen, described in the preceding paragraph; the other hydrocarbons are called *heavy hydrocarbons*. The chief of these are olefiant gas C_2H_4, and ethane C_2H_6. Both of these gases, like marsh gas, are the result of the metamorphism of carbonaceous matter, during the formation of the coal, but unlike marsh gas, they have been produced in the absence of water, and as a result they contain a larger percentage of carbon than marsh gas. They always exist in common with marsh gas, as occluded gases in coal seams, but to a far less extent. Each of these gases possesses a higher illuminating power, burning with a brighter flame than marsh gas. This is due to the larger percentage of carbon present in their composition. Their remaining properties are very similar to the properties given for marsh gas; they, however, when present in a firedamp mixture, lower the temperature of ignition, and render the mixture more dangerous than it would be otherwise.

Constants for Mine Gases.—The following table shows the symbols, specific gravities, and relative velocities of diffusion and transpiration of the principal mine gases, arranged in the order of their specific gravities, air being taken as 1. The values given in the next to the last column of this table were obtained by experimenting with the gases, and agree quite closely with the calculated values given in the preceding column. From this column we see that 1,344 volumes of marsh gas will diffuse in the same time as 1,000 volumes of air, or 812 volumes of carbonic-acid gas.

TABLE OF MINE GASES.

Name of Gas.	Symbol.	Specific Gravity.	$\frac{1}{\sqrt{\text{Sp. Gr.}}}$	Relative Velocity of Diffusion. (Air = 1.)	Relative Velocity of Transpiration. (Air = 1.)
Air		1.00000	1.0000	1.000	1.0000
Carbonic acid	CO_2	1.529	.8087	.812	1.2371
Sulphureted hydrogen	H_2S	1.1912	.9162	.95	
Oxygen	O	1.1056	.9510	.9487	.903
Olefiant	C_2H_4	.978	1.0112	1.0191	1.788
Nitrogen	N	.9713	1.0147	1.0143	1.0303
Carbonic oxide	CO	.967	1.0169	1.0149	1.034
Steam	H_2O	.6235	1.2664		
Marsh gas	CH_4	.559	1.3375	1.344	1.639
Hydrogen	H	.06926	3.7794	3.83	2.066

Carbonic-oxide gas CO, often called *whitedamp*, is a chemical compound consisting of 1 atom of carbon united to 1 atom of oxygen. To a certain

extent it occurs as an occluded gas in coal. It is chiefly formed, however, in coal mines, by the slow combustion of carbonaceous matter in the gobs or waste places of the mine, where the supply of air is limited. It is always the product of the slow combustion of carbon in a limited supply of air. It is therefore one of the chief products of gob fires, and is also a product of the explosion of powder in blasting. This gas often fills the crevice made behind a standing shot, and causes the flash that takes place when the miner puts his lamp behind such shot to examine the same. This gas is formed in large quantities whenever the flame of a blast or explosion is projected into an atmosphere in which coal dust is suspended. The force of a blast often blows the dust into the air, and the flame acting on it distils carbonic-oxide gas.

Carbonic-oxide gas is lighter than air, having a specific gravity of .967, and it therefore accumulates near the roof and in the higher working places. It is colorless, odorless, and tasteless. It is combustible, burning with a light-blue flame. This is the flame often seen over a freshly fed anthracite fire. It is also a supporter of combustion, being the only mine gas that burns and also supports combustion. This property leads to very important results in mines, inasmuch as it lengthens the flame of a lamp or the flame of a blast. Any flame is fed by this gas, and is thereby transmitted through the mine airways, from one point to another. The same property extends very widely an otherwise local explosion. This gas has the widest explosive range of any gas known to mining, except hydrogen. The effect of its presence in firedamp mixtures is always to widen the explosive range of the firedamp, causing it to become explosive in larger and smaller proportions than it otherwise would. Carbonic-oxide gas is a very poisonous gas, and acts on the human system as a narcotic, producing drowsiness or stupor, followed by acute pains in the head, back, and limbs, and afterward by delirium. It acts, when breathed into the lungs, to absorb the oxygen from the blood, or, in other words, poisons the blood.

Carbonic-oxide gas is detected in mine workings by its effect on the flame of a lamp, which burns more brightly in the presence of the gas, and reaches upwards as a slim, quivering taper, having often a pale-blue tip that, however, is not readily observed.

Carbonic-acid gas CO_2, often called *blackdamp* or *chokedamp*, is a chemical compound consisting of 1 atom of carbon united to 2 atoms of oxygen. It is heavier than air, having a specific gravity of 1.529. It therefore accumulates near the floor or in the low places of the mine workings. It is always the result of the complete combustion of carbon in a plentiful supply of air, and is a product of the breathing of men and animals, burning of lamps, or any other complete combustion. It is always present in occluded gases.

Carbonic-acid gas is a colorless, odorless gas, but possesses a peculiarly sweet taste, which may be detected in the mouth when it is inhaled in large quantities. It is not combustible, nor is it a supporter of combustion. Lamps are at once extinguished by it. It diffuses slowly into the atmosphere, and is a difficult gas to remove in ventilating. It is not poisonous, but acts to suffocate by excluding oxygen from the lungs. Its effect, when breathed for any length of time, is to cause headache and nausea, followed by weakness and pains in the back and limbs; when present in larger quantities, it causes death by suffocation. This gas, when present in firedamp mixtures, has the opposite effect from that of carbonic-oxide gas, inasmuch as it narrows the explosive range of the firedamp, and renders such mixtures inexplosive, which would otherwise be explosive (see Firedamp).

Carbonic-acid gas is detected in the mine air by the dimness of the lamps and by their extinguishment when present in larger quantities. It should always be looked for at the floor, and in low places of the mine workings.

Sulphureted hydrogen H_2S occurs at times as an occluded gas in coal seams, but more often exudes from the strata immediately underlying or overlying those seams. It is generally supposed to be formed by the disintegration of pyrites in the presence of moisture. It is heavier than air, having a specific gravity of 1.1912. It is a colorless gas, having a very disagreeable odor resembling that of rotten eggs, and is known to the miners as *stinkdamp*. It is an exceedingly dangerous gas when occurring in considerable quantities. When mixed with 7 times its volume of air, it is violently explosive. It is extremely poisonous, acting to derange the system when breathed in small quantities, and, when inhaled in larger quantities, it produces unconsciousness and prostration. Its smell serves as the best means for its detection.

Firedamp.—The general term *firedamp* relates to any explosive mixture of marsh gas and air, although in some localities this term is understood as referring to any mixture of marsh gas and air whatever, whether explosive or otherwise. Many persons speak of pure marsh gas as firedamp. The first meaning given above, however, is the general acceptation of the term.

Pure marsh gas when present in small quantities in the air burns in the flame of the lamp without explosion. As the quantity of the gas is increased, the effect on the flame of the lamp is at once noticeable. As the proportion of gas in the air is further increased, and approaches the lower explosive limit, the lamp flame enlarges, snaps, and crackles. When the proportion of gas to air is 1 to 13, slight explosions occur within the lamp, the flame of the lamp jumping violently. As the proportion of gas is increased, the violence of the explosion is augmented until it reaches a maximum, when the proportion of gas to air is 1 to $9\frac{1}{2}$ (exactly, 1:9.38). This is the proportion of gas and air in firedamp, when at its maximum explosive violence. From this point, as the quantity of gas is still further increased, the violence of the explosion decreases, until it becomes very feeble when the proportion of gas and air is 1 to $5\frac{1}{2}$, and ceases altogether beyond this point. The explosive limits of marsh gas, or the limits of firedamp mixtures, are then as follows: Lower limit, 1 volume of gas to 13 volumes of air; higher limit, 1 volume of gas to $5\frac{1}{2}$ volumes of air. These limits refer to pure firedamp, or, in other words, a firedamp mixture consisting of pure marsh gas and air.

It rarely happens that firedamp, as found in mine workings, is pure, but contains admixtures of other gases, such as carbonic-acid gas CO_2, carbonic-oxide gas CO, and heavy hydrocarbons.

Afterdamp.—The term *afterdamp* relates to the gaseous mixture that exists in mine workings after an explosion of gas. The composition of afterdamp is exceedingly variable, and admits of no general analysis that can be applied with certainty to any one explosion. The conditions that obtain in an explosion are so manifold, and control so completely the character of the gases formed, that it is impossible to give more than a general analysis of afterdamp.

The chief products of the complete explosion of pure firedamp are carbonic-acid gas, watery vapor, and nitrogen (see page 343). The explosion of firedamp is seldom, however, complete. Where a large body of gas has exploded, the air-current in the mine workings does not furnish sufficient air for the complete combustion of the firedamp, and as a result, a large amount of carbonic-oxide gas is formed, and is present in the afterdamp of the explosion. The presence of this gas (CO) renders the afterdamp far more dangerous than it would otherwise be, for two reasons: The gas itself is very poisonous, and its presence is not at once detected by the zealous men that are working to rescue their fellow workmen. The lamps burn very brightly in this gas, and the rescuers press forward unconscious of their real danger until overcome by the effects of the gas. The presence of coal dust in suspension in the mine air at the time of the explosion, or thrown into the air by the force of the explosion, results at once in the production of a large amount of carbonic-oxide gas. It is a well-known fact, also, that carbonic-acid gas CO_2, formed as a direct product of the explosion, or which may be present in the mine air before the explosion, coming in contact with the incandescent carbon of the coal dust, is converted by it, at the high temperature of the flame, into carbonic-oxide gas CO. We observe, therefore, that an explosion, in all its effects, tends to the rapid and abundant production of this most dangerous gas.

The other products of an explosion are numerous, but for the larger part, unimportant, except as they do not support life. We have mentioned and described only those gases forming the larger portion of the afterdamp, or constituting the active agents in an explosion.

Occurrence of Gases in Mines.—Most of the gases occurring in mines are occluded in the coal or the strata adjacent to the coal seam. These occluded gases differ widely in different coals, but are chiefly marsh gas with varying quantities of heavy hydrocarbons (olefiant gas, ethane, etc.) and carbonic-acid gas to a limited extent. In some coals, a large percentage of nitrogen gas is occluded, which, however, transpires very slowly into the atmosphere. Sulphureted hydrogen, when present, usually exudes from the underlying or overlying strata of the coal seam. These occluded gases are the result of coal formation, according to the best authorities and evidence. They exist in the pores of the coal under considerable pressure due to the weight of the

superincumbent strata. When the strata adjacent to the coal seam are impervious to gases, the occluded gases remain pent up, and we have what is called a *gaseous seam*. The tendency of the gas is always to escape to the surface or into the mine workings, at the first opportunity.

These gases have each their separate effects, and their combined effect is sometimes very complicated. We can only study to become familiar with the separate characteristics of each of these gases, and judge of their combined effect when present in firedamp mixtures. For example, one effect of all these gases when present in firedamp mixtures is to dilute the firedamp, and to that extent weaken its explosive force. Dilution of the firedamp by carbonic-acid gas CO_2 decreases very rapidly the explosiveness of the firedamp. When carbonic-acid gas is present in firedamp to the extent of one-seventh its volume, explosion ceases altogether; in other words, the firedamp is rendered inexplosive. The effect of smaller quantities of this gas is to contract the explosive limits of the firedamp as well as to weaken the explosion. The effect of carbonic-oxide gas CO when present in firedamp mixtures is likewise to dilute the firedamp. The flame, however, is lengthened by this gas, and the explosive limits of the firedamp mixture are *widened*. In other words, mixtures of marsh gas and air, which were not explosive mixtures, are rendered explosive by the presence of carbonic-oxide gas.

The chief source of the other mine gases lies in the slow combustion of carbonaceous matter in the gob, gob fires, burning of lamps, breathing of men and animals, etc. The table on page 353 shows the percentage of occluded gases in a number of coals and their volume at normal temperature and pressure.

Gas Feeders (Pockets).—The occluded gas of a coal seam escapes whenever opportunity is offered, and accumulates in the pockets and crevices of the adjoining strata, forming what are called *gas feeders*. These constitute a very dangerous element in the mining of gaseous seams, inasmuch as when such a crevice or feeder is tapped by the miner's drill, the gas, which is usually under heavy pressure, blows out in a large volume, at times even blowing the drill from the hole.

Pressure of Occluded Gases.—Occluded gases exist under a pressure that is proportionate to the weight of the overlying strata. Numerous experiments in England, France, and Belgium show that the pressure of gases occluded in coal seams frequently amounts to from 10 to 16 atmospheres, and in some cases has reached 32 atmospheres. These high pressures of occluded gases manifest themselves frequently in the boring of gas wells, where the tools are at times blown from the bore hole.

PRESSURE OF OCCLUDED GAS.

Name of Mine.	Depth of Hole. Feet.	Pressure. Pounds.
Elmore mine, main bed	8.53	4.36
Hetton mine, Hutton bed	8.98	6.96
Eppleton mine, Hutton bed	46.90	36.14
Balden mine, Bensham bed	31.85	71.41
Harris Navigation mine	32.80	22.04
Merthyr Vale mine	49.20	39.67
Celynen mine	54.48	68.32
Harton mine (1,214 ft. deep)	16.24	196.30
Harton mine	27.55	230.44
Harton mine	37.13	294.45

Amount of Gas.—Experiments made by the Prussian Firedamp Commission have given results varying from 357 to 2,400 cu. ft. of gas liberated per ton of coal mined. Mr. Chesneau gives 1,377 cu. ft. at the Herin mine, Anzin. Experiments at the Ronchamp mines give 883 cu. ft.

Outbursts of gas are frequent occurrences in some coal seams. They are caused by the occluded gas finding its way to a vertical crevice or cleat in the

GASES ENCLOSED IN THE PORES OF COAL AND EVOLVED IN VACUO AT 212° F.—(*Thomas.*)

Name of Colliery.	Quality.	CO_2	O	CH_4	N	Quantity.	
						c. c. per 100 Grams.	Cu. Ft. per Short Ton.
Navigation	Steam.	13.21	.49	81.64	4.66	250.0	80
Dunraven	Steam.	5.46	.44	84.22	9.88	218.0	70
Cyfarthfa	Steam.	18.90	1.02	67.47	12.61	147.0	47
Bute	Steam.	9.25	.34	86.92	3.49	375.0	120
Bonville's Court	Anthracite.	2.62		93.13	4.25	555.0	178
Watney's	Anthracite.	14.72		84.18	1.10	600.0	192
Plymouth Iron Works	Bituminous.	36.42	.80		62.78	55.9	18
Cwm Clydach	Bituminous.	5.44	1.05	63.76	29.75	55.1	18
Bettwys	Bituminous.	22.16	6.09	2.68	69.07	24.0	8

GASES ENCLOSED IN THE PORES OF COAL AND EVOLVED IN VACUO AT 212° F.—(*H. LeChatellier.*)

Locality.	CH_4	CO_2	N	O	Analyst.
Dunraven mine (blowers)	96.70	.47	2.79		J. W. Thomas.
Dunraven mine (bore hole)	96.50	.44	3.02		J. W. Thomas.
Garswood mine	84.16	.86	12.30	2.65	W. Kellner.
Garswood mine (blowers)	88.86	.41	8.90	1.83	W. Kellner.
Clamorgan mine (blowers)	93.01	.27	5.94	.78	W. Kellner.
Dombran mine (blowers)	95.11	.48	4.07	.34	Austrian Firedamp Commission.
Karwin mine	94.59	.18	4.48	.75	
Karwin mine (blowers)	99.10	.20	.70		
Hruschau mine	79.16	.19	17.04	.61	
Hruschau mine (blowers)	87.93	.83	10.25	.99	
Peterswald mine (blowers)	90.00	.15	9.25	.60	
Segen Gottes mine	83.51	1.17	15.02	.30	Sauer.
Segen Gottes mine (bore hole)	87.16	1.11	11.73		Sauer.
Liebe Gottes mine (bore hole)	77.69	3.77	18.48	.06	Sauer.

GASES ENCLOSED IN THE PORES OF COAL AND EVOLVED IN VACUO AT 212° F.—(*Schondorff.*)

Locality.	CH_4	C_2H_6	H	CO_2	$N+O$
Blowers.					
Bonifacius mine at Kray (Essen)	90.94		1.40	.30	7.36
Consolidation mine at Schalk (Westphalia)	89.88		5.84	.67	3.61
König mine at Neunkirchen (Saarbruck)	84.89	1.62		.65	12.84
Oberkirchen mine at Schaumburg	60.46	37.64	2.11	2.56	
	93.66	.88		.63	4.80
Cavities in the roof, Lothringen mine at Castrop (Westphalia)	27.95		1.35	.45	70.25
New Iserlohn mine at Lawgendren (Westphalia)	4.75		.09	1.34	65.00
	4.00	.06		.40	95.00

coal seam, as illustrated in Fig. 2, and the pressure of the gas thus becomes distributed over a large area. Thus, a pressure of 10 atmospheres of a gas feeder becoming distributed over an area of 200 sq. ft. results in a total pressure of upwards of 2,000 tons, upon a comparatively small area of coal.

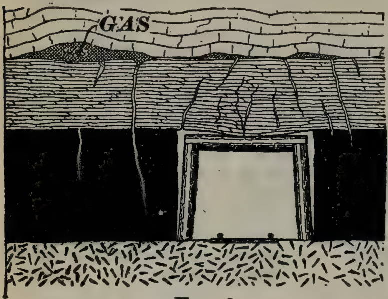


FIG. 2.

As mine openings approach proximity to such a locality, this pressure manifests itself by bursting the coal from its position in the face, and throwing it into the entries, in some cases completely blocking the openings or passageways. Such an occurrence is termed an *outburst.* It is frequently accompanied by thunderings and poundings, which manifest themselves for several days previous to the actual outburst of gas. These poundings are taken as a warning by the miners experienced in such regions. The poundings are probably the result of the gas working its way from one crevice to another, always advancing closer and closer to the mine openings, where they finally burst forth with extreme violence.

Testing for Gas by Lamp Flame.—Marsh gas and firedamp are detected in mine workings by the small flame cap that envelopes and surmounts the flame of the lamp in a firedamp mixture. This flame cap is caused by the gaseous mixture, which burns as it comes in contact with the flame. The proportion of gas in the mixture determines the height of the flame cap. When testing for gas, the lamp flame is first reduced to a small, uniform size, and although this is not a universal practice, it has the advantage of giving uniform results. The lamp is held in an upright position, in one hand, while the eyes are carefully screened by the other hand from the glare of the light, the lamp being slowly raised toward the roof where gas is suspected. The flame is carefully watched for the first appearance of a cap, and the height of the cap is carefully noted. Many lamps are provided with a graduated scale set opposite to the flame, so that the height of a cap may be estimated with accuracy. After the observation, the lamp is quietly and promptly withdrawn from the gas. Should flaming occur within the lamp, as sometimes happens when it is raised too quickly, or when the gaseous mixture is strong, the lamp should be withdrawn carefully and not with undue haste, as there is danger of the flame of the gases burning within the lamp being forced through the gauze by a rapid movement. This requires great presence of mind on the part of the person using the lamp.

In Fig. 3 the heights of flame cap due to the presence of different proportions of marsh gas are shown. These heights, as given, refer to the experimental heights of flame cap obtained with pure marsh gas. It should be observed, however, that the presence of other gases in the firedamp will vary its explosive character, and this fact very materially modifies the explosiveness of certain caps. For example, in the experiments on pure marsh gas, a 2″ flame cap was found to be inexplosive; while, in the mine, and with the variable character of the firedamp mixtures usually found there, a flame of $1\frac{3}{16}$ in. is often found to indicate explosive conditions. Again, flames of even less height than this often indicate dangerous conditions, especially where the coal is inflammable and there is much fine dust present in the atmosphere. These conditions account readily for the various statements that we commonly see in regard to the explosiveness of certain flames. In fact, each fire boss learns, after years of experience, to depend wholly on his

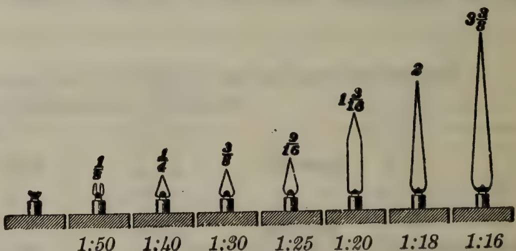


FIG. 3.

own knowledge, guided by the conditions that exist in the workings and with which he has become familiar.

SAFETY LAMPS.

The **safety lamp** is designed to give light in gaseous workings without the danger of igniting the gases present in the atmosphere. The principle of the safety lamp depends on the cooling effect that an iron-wire gauze exerts on flame. It is a well-known fact that all gases ignite at certain fixed temperatures, and if this temperature is decreased from any cause, the flame is extinguished.

Use of Safety Lamps.—Safety lamps are used for two general purposes in the mine, and may be classified under two heads: (*a*) lamps for general use; (*b*) lamps for testing for gas.

Safety Lamps for General Work.—The essential features of a lamp designed for general mine work are: (1) safety in strong currents; (2) good illuminating power; (3) security of lock fastening; (4) freedom from flaming; (5) security against accident; (6) simplicity of construction. The conditions under which a lamp is placed at the working face differ from those that attend the testing for gas. The illuminating power of the lamp must be good, so that the workman can see clearly what he is doing. The lamp must not be too sensitive to gas, or its tendency to flame will necessitate that a careful watch be kept of it, and this would interfere with the prosecution of the miner's work. Again, the miner is too often careless or neglectful of his lamp, and would fail to give it the required attention. The lamp is often upset, and is apt to be broken by flying coal, or by a fall, unless carefully protected. The lamp should be so securely locked as not to permit of any tampering on the part of the miner without its being detected in the lamp room. In order that the lamp may be thoroughly and rapidly cleaned, its construction should be simple. The lamp should be easily taken apart and put together again after it is cleaned.

Lamps for Testing.—The essential features of a lamp for testing purposes are: (1) free admission of air below the flame; (2) no reflecting surface behind the flame; (3) ability to test for a thin layer of gas at the roof. When testing for gas, it is important to have a free admission of the air below and around the flame, as the flame cap is very sensitive and is interfered with seriously by the conflicting ascending and descending currents in a lamp in which the air enters above the flame. A more uniform cap will be given where the currents ascend quietly around the flame. This feature is very important to the production of a good flame cap, and it is this feature that makes the Davy lamp such a favorite among fire bosses. In order that a flame cap shall be readily observed, there should be no reflection behind it, as the eye is easily deceived under these conditions. A scale by which the height of the flame cap may be accurately measured, is a convenient feature in many lamps for testing purposes.

In the use of the common Davy lamp in testing for gases, it is a common, although dangerous, practice to turn the lamp on its side and place it close up against the roof. In this position, the flame is very apt to pass through the gauze, from two causes: The gauze is readily heated, because the flame cap is close against it, and when heated, affords no protection against the passage of the flame and the ignition of the gas outside the lamp. Again, in this position, small particles from the roof are apt to fall upon the gauze, and this may often assist in the passage of the flame through the gauze. A dirty gauze is unsafe. When the lamp is turned sideways, the gauze may become smoked by contact with the flame, and this smoke, or deposit of carbon, assists greatly the passage of flame through the gauze. Another common and dangerous practice on the part of the fire boss is to brush the gas down on the lamp with his cap. By so doing, there is great danger of the flame being blown through the gauze and igniting the gas that may be present. On these accounts, it is essential that a good lamp for testing purposes shall be able to draw its air from a point close to the roof, in cases where it is necessary to do so. This is often accomplished by an extra tube, which is supplied with the lamp, and which may be taken off the lamp when not in use. This tube extends up the outside of the lamp to the top.

An important feature of a lamp for testing purposes is the uniformity of its flame. A more uniform flame is obtained in the use of alcohol instead of the lard oil commonly used in the safety lamp.

Detection of Small Percentages of Gas.—The Davy lamp in the hands of a careful person may be made to detect the presence of gas in quantities as low as 3%. It is claimed by some fire bosses that 2% of gas may be detected with a good Davy. For the detection of small quantities of gas, specially constructed lamps have been used. These lamps are designed to burn alcohol or hydrogen, giving a non-luminous flame. Among these may be mentioned the Pieler lamp, burning alcohol, which it is claimed will detect as small a quantity of gas as ¼%. A device known as the *Clowes gas tester* has been invented, and may be attached to many safety lamps. It consists of a hydrogen tube that is designed to furnish a small stream of hydrogen to the lamp flame when testing for gas. Surrounding the wick of the lamp is a closely fitting cone, to which the hydrogen from the tube is supplied. When the lamp is to be used for testing for gas, the wick is lowered, extinguishing the oil flame after the hydrogen is turned on. It is claimed that gas may be detected in as small quantities as ¼% by this apparatus attached to any good safety lamp admitting its air below the flame.

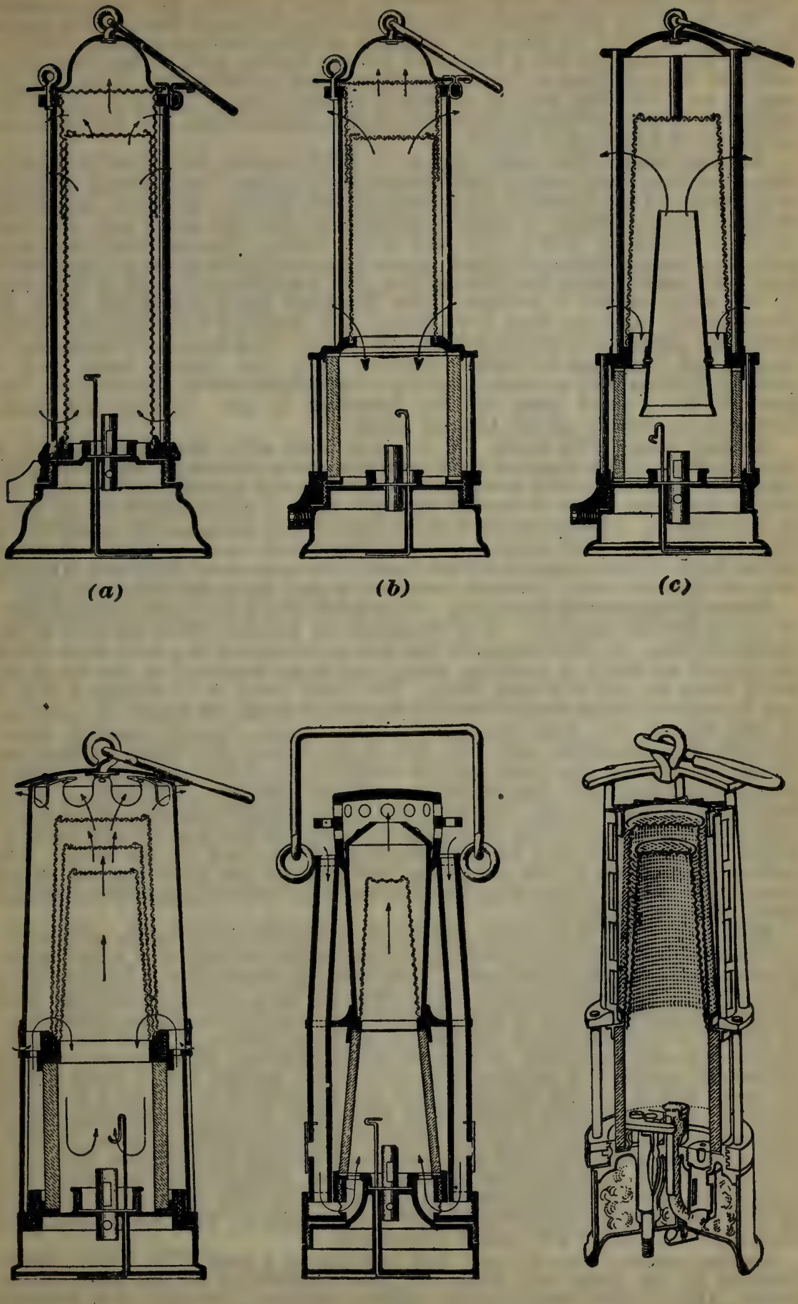
The *Shaw gas tester* is useful for determining the percentage of marsh gas in the mine air, but it cannot be applied at the face, and samples of gas must be taken to the surface for analysis.

Oils for Safety Lamps.—Most safety lamps burn vegetable oils, which are considered the safest for mining use, and so reported by the English Mine Commission. Such oils are rape-seed oil and colza oil, made from cabbage seed. Seal oil is also largely used, and was regarded as a safe oil by the English Mine Commission. Seal oil affords a better light than vegetable oils, and in its use there is less charring of the wick. A mixture of 1 part of coal oil to 2 parts of rape or seal oil is often used, and improves the light, but the smoke from the flame is increased. The Ashworth-Hepplewhite-Gray lamp is constructed to burn coal oil, or a mixture of coal and lard oil. The Wolf lamp is especially designed for burning naphtha or benzine. Special tests have been made to prove the safety of using such a fluid in this lamp, and resulted in demonstrating the fact that the lamp was safe under any conditions that might arise. A thorough test was made, the oil vessel of the burning lamp being heated to 180° F., at which point the lamp was extinguished without manifesting any dangerous results.

Types of Safety Lamps.—In the year 1815, Sir Humphrey Davy and George Stevenson, the latter a poor miner, discovered, simultaneously, that flame would not pass through small openings in a perforated iron plate. This led to the construction of what are known as the Davy, and the Stevenson or "Geordy," lamps. The Davy lamp is still a great favorite among fire bosses for the detection of gas in mine air. Inasmuch as all safety lamps, of which there are a large number, depend on the same principle, we will only describe such lamps as possess essential features, and which show important improvements and the gradual developments in safety-lamp construction.

Davy Lamp.—Fig. 4 (*a*) shows a wire gauze cylinder about 5 in. in height and 1¾ in. in diameter, surmounted by a gauze cap 2 in. in depth. The gauze, which has 28 wires to the inch, or 784 apertures to the square inch, is fastened to a brass standard, which secures it to the oil cup or lamp below. The gauze at the top of the lamp is doubled by the cap, which gives greater security at this point, where the flame tends to pass through the gauze more quickly, and where the gauze is more readily burned out. The mixture of gas and air enters the lamp in the lower part of the gauze, and burns within the lamp, the products of combustion passing out through the upper portion of the gauze cylinder. This lamp gives a good flame cap, on account of the free access of the air below the flame, which prevents smoking and increases the illuminating power of the lamp. As a lamp for general use, the Davy lamp, however, is unsafe, on account of its liability to flame. In many mining localities the use of this lamp is prohibited by law, except for purposes of examining for gas, when it must be used solely by properly authorized fire bosses. The flame of the lamp is also unprotected from the force of rapid air-currents, and is not safe when the velocity of the current exceeds 6 ft. per second. The illuminating power of the lamp is also not sufficient for general work.

Clanny Lamp.—The unbonneted Clanny lamp, Fig. 4 (*b*), is constructed according to the same principles as the Davy lamp, differing only in the fact that the lower part of the wire gauze surrounding the flame is replaced by a strong glass cylinder or chimney. The purpose of this is to increase the illuminating power of the lamp. The lamp, when clean, gives a good light, but the entrance of the air at a point above the flame, and its descent



(a) (b) (c)

(d) (e) (f)

FIG. 4.

within the lamp to the flame, causes the lamp to smoke, due to the conflict of the ascending and descending air-currents within the lamp. The smoke becomes deposited on the glass chimney, which interferes greatly with the light. This lamp is not a good one for gas testing, and in fact cannot be used for that purpose to any advantage. The unbonneted Clanny is not safe in an air-current having a velocity greater than 8 ft. per second. The bonneted Clanny obviates this difficulty to a large extent, but increases the tendency of the lamp to smoke.

Mueseler Lamp.—This lamp, Fig. 4 (*c*), in all respects resembles the Clanny lamp just described, except that the tendency in the Clanny lamp to smoke is overcome in the Mueseler by increasing the draft by means of an interior wrought-iron chimney or tube, supported within the lamp, and reaching down to within an inch of the base of the flame. The air enters the lamp as in the Clanny, above the flame, but is deflected downwards by the central tube, and passes under the edge of this tube, ascending through it to the top of the lamp, where it escapes. The Mueseler lamp is a better lamp for illuminating purposes than the Clanny, and presents more security, when bonneted, against explosions within the lamp. This lamp will withstand a current of very much higher velocity than the Clanny lamp, and is reputed to be safe in a current having a velocity of 100 ft. per second. The lamp is not a good lamp for the detection of gas. It does not flame, however, as quickly as the Clanny lamp.

Marsaut Lamp.—This lamp, Fig. 4 (*d*), is built after the Clanny lamp in every respect, but is supplied with multiple-gauze chimneys, one within the other, the effect of which is to increase the security against explosion of gas within the lamp. The bonneted Marsaut lamp is a peculiarly strong lamp in this respect. The gauze used in the caps of this lamp has 934 apertures to the square inch. This lamp is often extinguished in an explosive mixture by the force of the explosion within itself. It gives a good light and is a good lamp for general work; it is not, however, a good lamp for testing for gas.

Ashworth-Hepplewhite-Gray Lamp.—This lamp, Fig. 4 (*e*), combines a number of characteristic features. It is designed for general work, as well as for testing for gas. It often happens that gas accumulates in a thin layer along the roof of an entry or working place, and is not detected by the use of the Davy lamp or any ordinary lamp. The Gray lamp is so arranged that it can be made to draw its air from the top of the lamp, by means of openings in the top of the four standards of the lamp, the air passing down through the standards, and into the lamp, below the flame. When not in use for testing, openings can be made in the lower part of the standards by moving a slide, and air enters at these openings. The lamp is essentially a bonneted Clanny. The glass chimney, however, as well as the gauze that surmounts it, is made in a conical form, the purpose of this being to diffuse the light upward for examination of the roof of the mine. The conical form given to the gauze also strengthens the lamp against explosions of gas within. This lamp is a very good all-around lamp, and possesses good illuminating power.

Wolf Lamp.—The Wolf lamp, Fig. 4 (*f*), is rapidly growing in popularity having been already introduced in a large number of mines in America and England, and on the Continent. This lamp is essentially a Clanny lamp with a free admission of air. It is compact and efficient, and has good illuminating power, and is also constructed in different forms, combining, as desired, any or all of the features of previous lamps. Two of its characteristic features, however, consist in a self-lighting arrangement accomplished by means of a percussive device, which ignites a wax taper within the lamp, and a locking device, which can be opened only with a powerful magnet. This relighting device is an important feature in any safety lamp for general use, inasmuch as the most dangerous conditions exist immediately after an explosion, and the miners are always left to grope their way in the dark. A large number of lives are lost, owing to the confusion that ensues, the men becoming bewildered and losing their way, when they are shortly overcome by the afterdamp of the explosion. This lamp permits of immediate relighting with safety to the men.

Locking Lamps.—The ordinary lock consists of a lead plug, which, when inserted in the lamp, will show the least tampering on the part of the miner. Other locks consist of an ordinary turnbolt operated by a peculiar key. Magnetic locks allow of the opening of the lamp only by means of a strong magnet kept in the lamp room.

Cleaning Safety Lamps.—Safety lamps should be thoroughly and regularly

cleaned and filled between each shift. Each lamp should then be lighted and inspected by a competent person before being given to the miner. A careful inspection of the gauze of the lamp is necessary, as well as of all the joints by which air may enter the lamp. It should be known to a certainty that each lamp is securely locked before leaving the lamp room.

Relighting Stations.—These stations are located at certain places in gaseous mines where they can be supplied with a current of fresh air, and where there is no danger from the gases of the mine. The lamp is apt to be overturned, or to fall, and is often extinguished thereby; and if these stations were not provided, the man would have to return with his lamp to the surface in order to have it relighted. Such a station is always located at the entrance of the gaseous portion of a mine, in cases where the entire mine does not liberate gas.

Illuminating Power of Safety Lamps.—The following table gives the illuminating power or candlepower of some of the principal lamps. The light of a sperm candle is taken as 1, or unity.

Name of Lamp.	Illuminating Power of Lamp.
Davy	.16
Geordy	.10
Clanny	.20
Mueseler	.35
Evan Thomas	.45
Marsaut, 3 gauzes	.45
Marsaut, 2 gauzes	.55
Marsaut, with Howat's deflector	.65
Ashworth-Hepplewhite-Gray	.65
Wolf	.90

EXPLOSIVE CONDITIONS IN MINES.

In the ventilation of gaseous seams, the air-current may be rendered explosive by the sudden occurrence of any one of a number of circumstances that cannot be anticipated. Among these are the following: (1) Derangement of the ventilating current. (2) Sudden increase of gas due to outburts, falls of roof, feeders, fall of barometric pressure, etc. (3) Presence of coal dust thrown into suspension in the air, in the ordinary working of the mine, or by the force of blasting at the working face, or by a blown-out, or windy, shot. (4) Pressure due to a heavy blast, or any concussion of the air caused by closing of doors, etc. (5) Rapid succession of shots in close workings. (6) Accidental discharges of an explosive in a dirty atmosphere. Any or all of these causes may precipitate an explosion at any moment. Hence, the condition of the air-current should be maintained far within the explosive limit. The explosive conditions vary considerably in different coal seams. The nature of the coal and its enclosing strata, its friability and inflammability, together with the character of its occluded gases, determine, to a large extent, the explosive conditions in the seam. Experience in any particular seam or district must always be the best guide, and furnish the best standard for determining the explosiveness of any given lamp flame. For example, a 2″ flame may be comparatively safe in a small mine where the coal is hard and not particularly flammable, while a 1½″ flame cap would be considered unsafe in mines where the conditions are more favorable to the generation of gas and formation of coal dust. The daily output of the mine and the general care that is enforced upon the miners at the working face are factors that should always be considered and taken into serious account in determining explosive conditions (see Testing for Gas by Lamp Flame).

Derangement of Ventilating Current.—The flow of the air-current must be uniform and continuous. Doors must be kept closed, since the mere setting open of a door, for a short period of time, is sufficient to precipitate a serious explosion. Any contemplated change in the current, by the erection of brattices, air bridges, stoppings, etc., should be carefully considered before the work is begun, and every precaution adopted to secure the safety of the

men. Derangement of the current may occur through a fall of roof upon the main airway, by which the area of the airway is reduced, which results in the reduction of the quantity of air passing in the mine. If this fall is not noticed at once, serious results may happen. The utmost vigilance is therefore required on the part of fire bosses and all connected with mine workings. The failure of the ventilating apparatus is another source that gives rise to the derangement of the current. As a rule, furnaces are not now employed for the ventilation of gaseous seams. There are, however, some furnaces in use in such seams, and these require constant attention lest the fire should burn low. Upon any accident occurring to the ventilating machinery, notice should at once be given to the inside foreman, and the men withdrawn as rapidly as possible.

A sudden increase of gas may occur at any time in a gaseous seam, owing to an outburst, which suddenly yields a large volume of gas and may render the mine air in that section extremely explosive. The men working on the return of such a current must be hastily withdrawn, and all lights extinguished. A heavy fall of coal in the mine workings or in the airways, or the tapping of a large gas feeder, produces the same effect in a less degree. The nearer the fall of roof takes place to the face of the workings, the more liable it is to be followed with a large flow of gas, inasmuch as the gas near the face has not had time to drain off, as in the case of old workings. This fact is always true in reference to new workings in a gaseous seam. The gas continues to flow freely for a considerable period, when its flow gradually decreases until it about ceases. When a large feeder has been tapped, it may be plugged for a time, if necessary, but the better practice is to allow it to flow freely and diffuse into the air-current, which should be sufficiently increased to dilute the quantity of gas given off and to render it inexplosive. The men upon the return air should be notified. It is dangerous practice to light these feeders.

When there is a large area of abandoned workings in the mine, any considerable fall of barometric pressure is usually followed by a large outflow of gas from the gobs or waste places of the mine. A fall of 1 in. in 5 hours represents a very rapid decrease of barometric pressure. At all large collieries there is, or should be, a good standard barometer located upon the surface near the shaft. In many cases, these barometers are self-recording, and are often provided with an automatic alarm that gives warning whenever a fall of barometric pressure occurs. This warning should at once be conveyed to the men in the workings, and every precaution adopted to avoid evil results. The fact is fairly well established that a fall of atmospheric pressure is not followed by an outflow of gas from the mine workings for the space of, say, 3 hours after such fall occurs. This statement must be regarded with caution, however, as it largely depends on the condition and extent of the abandoned workings. Where these are full of gas, its expansion affects the condition of the airways much more quickly than in cases where these working places are partly ventilated.

Effect of Coal Dust in Mine Workings.—According to the greater or less flammability of the coal, the presence of fine dust in the airways and workings of the mine becomes a dangerous factor. Certain coals are extremely friable and are reduced readily to fine dust, which is thrown into suspension in the air-current by the ordinary operations of the miners in their work, as well as by the concussion of the air from numerous causes, and by the movement of cars and the traveling of men and animals upon the various haulways and passageways. For a long time it was questioned whether the presence of dust was a dangerous factor, except where there was also a small percentage of gas in the air. Evidence, however, has well established the fact that coal dust of itself is a dangerous element, and may often be the sole cause of an explosion, when acted upon by a flame of sufficient intensity and magnitude. The action of the flame is to distil carbonic-oxide gas CO from the fine particles of dust suspended in the air. The explosion of the gas thus formed causes a further disturbance and raises a larger supply of dust, which likewise contributes to the liberation of fresh quantities of gas, and thus an explosion is generated and transmitted. Small quantities of marsh gas greatly increase the violence of this action, but explosions in flouring mills and well-ventilated coal bins establish the fact that such occurrences are not dependent on the presence of marsh gas.

Too much faith must not be placed in the use of water by sprinkling for laying the dust. This has a beneficial effect in the immediate vicinity, but a large amount of water is required to render an untidy working place safe

at firing time. Better practice is to allow no accumulations of dust at the face. This should be regularly loaded out with the coal.

Pressure as Affecting Explosive Conditions.—Gaseous mixtures that are not explosive in the ordinary condition of a mine, often become explosive under the momentary pressure to which they are subjected by heavy blasting, and, in some instances, this may occur from the concussion of the air caused by the quick shutting of a door. In the latter case, however, the explosive condition of the air would necessarily have to be close to the limit, in order for such a slight occurrence to precipitate an explosion. The factor of pressure as increasing the explosiveness of gaseous mixtures should be considered and constantly borne in mind.

Rapid Succession of Shots in Close Workings.—It constantly happens that two, three, or more shots are fired by means of fuse or touch squibs in a single chamber or heading, where the circulation of air is not always the best. The practical effect is that a considerable quantity of carbonic-oxide gas *CO* is produced by the firing of the first shot, and this gas does not have time to diffuse or become diluted by the air-current before it is fired by the flame of the following shots. An explosion may often be precipitated by such an occurrence, if the workings are at all dusty. Two shots at the most are all that should be fired at one time in a close chamber or heading.

Mine Explosions.—The explosion of gas in a mine usually arises from the ignition of an explosive mixture of gas and air called *firedamp*, which has accumulated in some unused chamber or cavity of the roof, or in the waste places of the mine, and has been ignited by a naked light, by the flame of a shot, or by a mine fire. The initial force of an explosion is generally expended locally, but the flame continues to feed upon the carbonic-oxide gas generated by the incomplete combustion of the firedamp mixture, and distilled also from the coal dust thrown into the air by the agitation. Air is required to burn this carbonic-oxide gas; this causes the flame to travel against the air-current, or in the direction in which fresh air is found. In the other direction, or behind the explosion, the flame is soon extinguished in its own trail when the initial force of the explosion is expended. The explosion continues to travel along the airways against the current as long as there is sufficient gas or coal dust for it to feed upon, or until its temperature is cooled below the point of ignition, by some cause such as, for example, the rapid expansion of the area of the workings. We observe the chief factor in transmitting an explosion is the presence of carbonic-oxide gas, which lengthens the flame and extends the effect.

The **recoil of an explosion** is the return of the flame along the path that it has just traversed. In the recoil, the flame burns more quietly, advances more slowly, and travels close to the roof. The evidence found at the point where a recoil took place, or an explosion turned back, has been sufficient to establish the fact that the recoil is caused primarily by a cooling of the temperature, probably caused very largely by an expansion of the area of the airway. Soot is often deposited at this point in considerable quantity, if the action of the flame is not such as to consume it. This fact alone shows the combustion at this point to have been incomplete. Immediately in the rear of the flame is a mixture of carbonic-oxide gas *CO*, which bursts into flame at the sudden stoppage of the advancing explosion. This is rendered possible by the flow of cold air from the adjacent chambers and workings along the floor of the airway. The flame now retreats, burning the trail of carbonic-oxide gas along the roof, fed by the cold air along the floor.

To Explore Workings After a Serious Explosion.—The shafts or slopes and the ventilating machinery should claim the first attention of those on the surface, and an effort should be made to reach the bottom as expeditiously as possible. Assistance from neighboring collieries, both in the way of skilled labor and advice, should also be requested. Should the shaft or slope need repairs before communication between top and bottom is restored, the person in charge on the surface should, in the meantime, see that props of the lengths in ordinary use, brattice boards, brattice cloth, and nails are brought to a convenient place for putting on the cage or car, and he ought also to collect all the tools likely to be required, such as axes, saws, hammers, etc. It is also important that rough tracings of the workings be prepared for the use of the leader of each squad of explorers. Officials will understand how useful these will be to those that are penetrating into workings about which every man of his squad may have been heretofore ignorant.

When the explorers have arrived at the bottom and are ready to proceed, there should be for each section, if more than one is operated upon, two

managers, each having his own squad of men, and his own particular duty to do. One may take charge of restoring the ventilation, the inspection of the workings, and the clearing of the roads; the other may appoint and have charge of the bottom man, the conveying of material, and the detailing of stretcher companies where required. They can consult and help each other in every difficulty, but system is necessary if the work is to be done in the shortest possible time.

The manager who has charge of the men in front should appoint two experienced men with good nerves to act as foremen, instructing them to inspect and report to him the condition of the workings within a short radius. He should then form the rest of his men into, say, three squads of three each, who will work together at stoppings or falls until separated by him, or until the end of the shift. Being near the bottom, it will probably be found that all is clear for three or four breast or stoop lengths, and stoppings are required to be put up. Material will be required for this, and when the cage is first sent to the top for it, it should not be kept there to enable the top man to put on a big load, but it should be sent down with all despatch, loaded with a half dozen each of props and brattice boards, with one piece of cloth and nails. This will allow a start to be made, and will prevent the anxious men from worrying over what to them is an unaccountable delay. Larger loads can be sent down in subsequent trips. For convenience in carrying, the brattice cloth may be cut in lengths to suit the gangways or headings with 2 or 3 ft. to spare. Squad No. 1 should be detailed to the first stopping. This may be put up with boards at top and bottom and cloth between. If the air-current is strong, a few of the following stoppings may be put up by squads No. 2 and No. 3, with cloth only stretched between two props. These can be very rapidly put up and will drive the ventilation forwards, thus allowing the firemen to extend rapidly the area of inspection. These stoppings can be completed by No. 1 detail. In a short time it may become impossible to proceed in this manner. The foul air will in all probability become more difficult to dislodge, and eventually one detail may be able to put up stoppings as quickly as the firedamp or chokedamp can be carried off. Part of what may be called the ventilating detail can now be transferred to the bearer detail, the duties of the latter having become heavier as the stoppings advanced. It is not an easy task to carry props long distances in a stooping posture, and when to that is added, it may be, the carrying out of the living or dead bodies, the men begin to fag very soon. But the person in charge here must see that the forward party is kept in material for stoppings so that no delay may occur on that account. A system of staging gives relief to the carrying parties.

To conclude with a few general remarks: Let those that have never yet assisted to explore a mine after an explosion be assured of this, that the chief requisites in a leader are a capacity for hard work and the ability to organize his men into a system, however roughly, whereby work will be best forwarded. It will not speed the work to say to a dozen or more men, generally, do this or that, neither is it beneficial to allow all the workmen to discuss matters and suggest plans. Those in charge ought to arrange what is to be done. Anything else results in noise and confusion. And let men that are sent from other collieries take with them their own tools and lamps. Those in charge ought to take note of the position, etc. of bodies found, and of every point which is likely to throw light on the cause or origin of the explosion. This can be more correctly done before the roads are disturbed by dust and travel. These notes might not only be the means of ascertaining the cause of explosion, but also of pointing out a way of prevention in the future.

In no case after an explosion should the air-current of the mine be reversed from its usual course, except only after careful consideration, because of the reliance placed by the entombed workmen on their knowledge of the direction in which the air should be moving; and the reversal of the current may drive the gases of the explosion upon them with disastrous results. Conditions must be allowed to remain as they exist, and the rescuers conform themselves to such conditions in the best manner possible.

QUANTITY OF AIR REQUIRED FOR VENTILATION.

The quantity of air required for the adequate ventilation of a mine cannot be stated as a rule applicable in every case. Regulations that would supply a proper amount of air for the ventilation of a thick seam would be

found to cause great inconvenience if applied without modification to the workings in a thin seam. Likewise, the ventilation of an old mine with extended workings, a large area of which has been abandoned, and in many cases not properly sealed off, will require, naturally, a larger quantity of air per capita than a newly opened mine or shaft. The natural conditions existing in rise and dip workings, with respect to the gases that may be liberated or generated in those workings, call for the modification of the quantity of air required in each case. For example, dip workings, where much blackdamp is generated, will require a larger quantity of air, or higher velocity at the working face, to carry off such damps; and rise workings, liberating a large amount of marsh gas, will likewise require a higher velocity at the working face. On the other hand, a reversal of these conditions, such as a large quantity of marsh gas being liberated in dip workings, or a similar amount of blackdamp being generated in rise workings, will require a comparatively low velocity of the air at each respective working place.

Quantity Required by State Laws.—The quantity of air required by the laws of the several States is generally specified as 100 cu. ft. per man per minute, and in many cases an additional amount of 500 cu. ft. per animal per minute is stated. This quantity is in no case stated as the actual amount of air required for the use of each man or animal, but is only the result of experience, as showing the quantity of air required for the proper ventilation of the average mine, based on the number of men and animals employed. The number of men employed in a mine is an indication of the extent of the working face, while the number of animals employed is an indication likewise of the extent of the haulage roads, or the development of the mine. These amounts refer particularly to non-gaseous seams.

The Bituminous Mine Law of Pennsylvania specifies that there shall be not less than 100 cu. ft. per minute per person in any mine, while 150 cu. ft. are required in a mine where firedamp has been detected.

The Anthracite Mine Law of Pennsylvania specifies a minimum quantity of 200 cu. ft. per minute per person. Each of these laws contains modifying clauses, which specify that the amount of air in circulation shall be sufficient to "dilute, render harmless, and sweep away" smoke and noxious or dangerous gases.

Quantity of Air Required for Dilution of Mine Gases.—To determine this requires a knowledge of the quantity of gas generated or liberated in the workings. The quantity of air for dilution should be ample, and should be such as not to permit the condition of the current to approach the explosive point. The ventilation should be ample at the face.

Quantity of Air Required to Produce the Necessary Velocity of Current at the Face.—This consideration modifies considerably the quantity of air required for the ventilation of thick and thin seams. The velocity of the current is dependent not only on the quantity of air in circulation, but on the area of the air passage. This area is quite small in thin seams, and often very large in thick seams. As a result, the velocity is often low at the face of thick seams, and insufficient for the proper ventilation of the face, although the quantity of air passing into such a mine may be very large. A certain velocity of the current is always required in order to sweep away the gases. This velocity depends on the character of the gases and the position of the workings. Heavy damps are hard to move from dip workings where they have accumulated; and, likewise, lighter damps accumulating at the face of steep pitches are hard to brush away, and the velocity of the current in these cases must be equal to the task of driving out these gases.

ELEMENTS IN VENTILATION.

The elements in any circulation of air are (*a*) horsepower, or power applied; (*b*) resistance of the airways, or mine resistance, which gives rise to the total pressure in the airway; (*c*) velocity generated by the power applied against the mine resistance.

Horsepower or Power of the Current.—The power applied is often spoken of as the *power upon the air*. It is the effective power of the ventilating motor, whatever this may be, including all the ventilating agencies, whether natural or otherwise. The power upon the air may be the power exerted by a motive column due to natural causes, or to a furnace, or may

be the power of a mechanical motor. The power upon the air is always measured in foot-pounds per minute, which expresses the units of work accomplished in the circulation.

Mine Resistance.—The resistance offered by a mine to the passage of an air-current, or the mine resistance, is due to the friction of the air rubbing along the sides, top, and bottom of the air passages. This friction causes the total ventilating pressure in the airway, and is equal to it. Calling the resistance R, the unit of ventilating pressure (pressure per square foot) p, and the sectional area of the airway a, we have, $R = p\,a$; that is to say, the total pressure is equal to the mine resistance.

Velocity of the Air-Current.—Whenever a given power is applied against a given resistance, a certain velocity results. For example, if the power u (foot-pounds per minute) is applied against the resistance $p\,a$, a velocity v (feet per minute) is the result; and since the total pressure $p\,a$ moves at the velocity v, the work performed each minute by the power applied is the product of the total pressure by the space through which it moves per minute, or the velocity. Thus, $u = (p\,a)\,v$.

Relation of Power, Pressure, and Velocity.—The relation of these elements of ventilation is not a simple relation. For example, a given power applied to move air through an airway establishes a certain resistance and velocity in the airway. The resistance of the airway is not an independent factor; that is to say, it does not exist as a factor of the airway independent of the velocity, but bears a certain relation to the velocity. *Power always produces resistance and velocity*, and these two factors always sustain a fixed relation.

This relation is expressed as follows: The *total pressure or resistance varies as the square of the velocity;* i. e., if the power is sufficient to double the velocity, the pressure will be increased 4 times; if the power is sufficient to multiply the velocity 3 times, the pressure will be increased 9 times. Thus, we observe that a change of power applied to any airway means both a change of *pressure* and a change of *velocity.*

Again, since the power is expressed by the equation $u = (p\,a)\,v$, and since $p\,a$, or the total pressure, varies as v^2, the work varies as v^3. From this it follows that, if the velocity is multiplied by 2, and, consequently, the total pressure by 4, the work performed $(p\,a)\,v$ will be multiplied by $2^3 = 8$. *We thus learn that the power applied varies as the cube of the velocity.*

MEASUREMENT OF VENTILATING CURRENTS.

The measurement and calculation of any circulation in a mine airway includes the measurement of (a) the velocity of the air-current, (b) of pressure, (c) of temperature, (d) calculation of pressure, quantity, and horsepower of the circulation.

These measurements should be made at a point in the airway where the airway has a uniform section for some distance, and not far from the foot of the downcast shaft or the fan drift.

Measurement of Velocity.—For the purpose of mine inspection, the velocity of the air-current should be measured at the foot of the downcast, at the mouth of each split of the air-current, and at each inside breakthrough, in each split. These measurements are necessary in order to show that all the air designed for each split passes around the face of the workings.

The measurement of the velocity of a current is best made by means of the anemometer. This instrument consists of a vane placed in a circular frame and having its blades so inclined to the direction of its motion that 1 ft. of lineal velocity in the passing air-current will produce 1 revolution of the vane. These revolutions are recorded by means of several pointers, each having a separate dial upon the face of the instrument, the motion being communicated by a series of gear-wheels arranged decimally to each other. Most anemometers are provided with a large central pointer that makes 1 revolution for each 100 revolutions of the vane. The dial for this pointer is marked by 100 divisions, which record the number of lineal feet of velocity. In very accurate work with the anemometer, certain constants are used as suggested by the instrument maker, but these constants are of little value in ordinary practice and are of doubtful value even in more accurate observations.

The measurement of the velocity of an air-current must necessarily represent only approximately the true velocity in the airway. The air travels with a greater velocity in the center of the airway, and is retarded at

the sides, top, and bottom by the friction of these surfaces. Hence, the air to a large extent rolls upon these surfaces, which naturally generates an eddy at the sides of airways. When measuring the air, the anemometer should be held in a position exactly perpendicular to the direction of the current, and moved to occupy different positions in the airway, being held an equal time in each position, or it may be moved continuously around the margin of the airway, and through the central portion. The person taking the observation should observe the caution of not obstructing the area of the airway by his body, as the area is thereby reduced, and the velocity of the current increased. The area of the airway is accurately measured at the point where the observations are taken.

To obtain the quantity of air passing (cubic feet per minute), multiply the area of the airway, at the point where the velocity is measured, by the velocity.

EXAMPLE.—The anemometer gives a reading of 1,320 ft. in 2 minutes, the height of the airway is 6 ft. 6 in., and its average width 8 ft. 8 in. What volume of air is passing in the airway per minute?

$$6\tfrac{1}{2} \times 8\tfrac{2}{3} \times \frac{1{,}320}{2} = 37{,}180 \text{ cu. ft. per min.}$$

The **measurement of the ventilating pressure** is made by means of a water column in the form of a water gauge.

Water Gauge.—The water gauge is simply a glass **U** tube open at both ends. Water is placed in the bent portion of the tube, and stands at the same height in both arms of the tube when each end of the tube is subjected to the same pressure. If, however, one end of the tube is subjected to a greater pressure than the other end, the water will be forced down in that arm of the tube, and will rise a corresponding height in the other arm, the difference of level in the two arms of the tube representing the water column balanced by the excess of pressure to which the water in the first arm is subjected. An adjustable scale graduated in inches measures the height of the water column. The zero of the scale is adjusted to the lower water level, and the upper water level will then give the reading of the water gauge. One end of the glass tube is drawn to a narrow opening to exclude dust, while the other end is bent to a right angle, and passing back through the standard to which the tube is attached, is cemented into the brass tube that passes through a hole in the partition or brattice, when the water gauge is in use. The bend of the tube is contracted to reduce the tendency to oscillation in the height of water column. (See Fig. 5.)

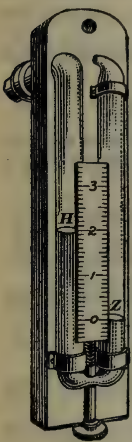


FIG. 5.

FIG. 6.

When in use, the water gauge must be in a perpendicular position. It is placed upon a brattice occupying a position between two airways, as shown at *A*, Fig. 6. The brass tube forming one end of the water gauge is inserted in a cork, and passes through a hole bored in the brattice. The water gauge must not be subjected to the direct force of the air-current, as in this case the true pressure will not be given. Fig. 6 shows the instrument as occupying a position in the breakthrough, between two entries. It will be observed that the water gauge records a difference of pressure, each end of the water gauge being subject to atmospheric pressure, but one end in addition being subject to the ventilating pressure, which is the difference of

pressure between the two entries. The water gauge thus enables us to measure the resistance of the mine *inbye* from its position between two airways. If placed in the first breakthrough, at the foot of the shaft, it measures the entire resistance of the mine, but if placed at the mouth of a split, it measures only the resistance of that split. It never measures the resistance *outbye* from its position in the mine, but always *inbye* (see Calculation of Pressure).

Measurement of Temperature.—It is important to measure the temperature of the air-current at the point where the velocity is measured, as the temperature is an important factor of the volume of air passing (see Expansion of Air and Gases, etc.).

Thermometers.—Thermometers measure changes in the temperature of the atmosphere by the contraction and expansion of mercury or spirits; or they may be made entirely of metal, and the changes of temperature are then measured by the expansion and contraction of the sensitive metallic portion. These latter are known as aneroid thermometers. The Fahrenheit thermometer is the one most commonly used in America. By this scale, the freezing point of water at the sea level is placed at 32° above zero; the boiling point of water at sea level is placed at 212° above zero, so that the space between these two points is divided into 180°.

Réaumur and Centigrade thermometers are used on the continent of Europe. Of these two, the first is generally used in Germany, and the second in France, but the latter is almost exclusively used by the scientists of all nations.

In the Réaumur thermometer, the freezing and boiling points are placed at 0° and 80°, respectively. In the Centigrade, the freezing and boiling points are placed at 0° and 100°, respectively.

To Convert Fahrenheit Into Centigrade.—(1) Subtract 32 and divide the remainder by 1.8, or multiply by $\frac{5}{9}$.

If a Fahrenheit thermometer registers 167°, what will be the register by a Centigrade thermometer?

$$\frac{167-32}{1.8} = 75° \text{ Centigrade.} \quad \frac{(167-32)5}{9} = 75° \text{ Centigrade.}$$

To Convert Centigrade Into Fahrenheit.—(1) Multiply by 1.8, or $\frac{9}{5}$, and add 32.

If the Centigrade thermometer registers 75°, what will be the register by a Fahrenheit thermometer?

$$75 \times 1.8 + 32 = 167° \text{ Fahrenheit.} \quad \frac{75 \times 9}{5} + 32 = 167° \text{ Fahrenheit.}$$

To Convert Fahrenheit Into Réaumur.—(1) Subtract 32, and divide by 2.25, or multiply by $\frac{4}{9}$.

If the Fahrenheit thermometer registers 113°, what will be the register by the Réaumur thermometer?

$$\frac{113-32}{2.25} = 36° \text{ Réaumur.} \quad \frac{(113-32)4}{9} = 36° \text{ Réaumur.}$$

To Convert Réaumur Into Fahrenheit.—(1) Multiply by 2.25, or multiply by $\frac{9}{4}$, and add 32.

If the Réaumur thermometer registers 36°, what will be the register by the Fahrenheit thermometer?

$$36 \times 2.25 + 32 = 113° \text{ Fahrenheit.} \quad \frac{36 \times 9}{4} + 32 = 113° \text{ Fahrenheit.}$$

To Convert Réaumur Into Centigrade.—Multiply by 1.25.

If a Réaumur thermometer registers 32°, what will be the register by a Centigrade thermometer?

$$32 \times 1.25 = 40° \text{ Centigrade.}$$

To Convert Centigrade Into Réaumur.—Multiply by .8.

If a Centigrade thermometer registers 40°, what will be the register by a Réaumur thermometer?

$$40 \times .8 = 32° \text{ Réaumur.}$$

Calculation of Mine Resistance.—The mine resistance is equal to the total pressure $p\,a$ that it causes. This mine resistance is dependent upon three factors: (a) The resistance k offered by 1 sq. ft. of rubbing surface to a current having a velocity of 1 ft. per minute. The *coefficient of friction* k, or the *unit of resistance*, is the resistance offered by the *unit* of rubbing surface to a current of a *unit* velocity. This unit resistance has been variously estimated by different authorities (see following table). The value most universally accepted, however, is that known as the Atkinson coefficient

(.0000000217). (*b*) The mine resistance, which varies as the square of the velocity. (*c*) The rubbing surface. Hence, if we multiply the unit resistance by the square of the velocity, and by the rubbing surface, we will obtain the total mine resistance as expressed by the formula $pa = ksv^2$.

TABLE OF VARIOUS COEFFICIENTS OF FRICTION OF AIR IN MINES.

	Pressure per Sq. Ft. Decimals of a Pound.
J. J. Atkinson's treatise	.0000000217
A. Devillez in Ventilation des Mines:	
Forchies	.000000008211
Crachet-Picquery	.000000008928
Grand Baisson	.000000008611
Average of 2, 3, and 4	.000000008585
Used in Ventilation des Mines	.000000009511
Arched Tunnels	.000000002113
Along a working face of coal	.000000014266
G. G. Andre, Atmosphere of Coal Mines	.000000022424
Peclet, Cheminee (Devillez, p. 112)	.000000003697
D. K. Clark	.000000002272
According to Goupilliere's Cours d' Exploitation des Mines, Vol. II, p. 389:	
D'Aubuisson	.000000001955
Navier	.000000001872
W. Fairley	.00000001
J. Stanley James	.00000000929
D. Murgue	.000000008242

It will be observed that J. J. Atkinson's coefficient is greatly in excess of any other, with the exception of Andre's. Fairley's is derived from an average taken between Atkinson, Devillez, and Clark, and, undoubtedly, it is an exceedingly simple coefficient to work out calculations with, as it will save a great mass of figures. James, in his work on colliery ventilation, reduces the coefficient still further on the authority of the Belgian Mine Commission, but he gives a most unwieldy figure to use.

Atkinson's figure is the one most in use, and if it is too high, it errs on the side of safety, and it is always advisable to have plenty of spare ventilating power at a mine. For this reason, and until a regular and thorough investigation, made by a commission of competent men, provides a standard coefficient, we prefer to abide by Atkinson's coefficient, and it is used in all our calculations.

Calculation of Power, or Units of Work per Minute.—If we multiply the total pressure by the velocity (feet per minute) with which it moves, we obtain the units of work per minute, or the power upon the air. Hence, $u = pav = ksv^3$, which is the fundamental expression for *work per minute*, or *power*.

The Equivalent Orifice.—This term, often used in regard to ventilation, evaluates the mine resistance, or, as will be seen from the equation given below for its value, it expresses the ratio that exists between the quantity of air passing in an airway and the pressure or water gauge that is produced by the circulation. This term was suggested by M. Daniel Murgue, and refers to the flow of a fluid through an orifice in a thin plate, under a given head. The formula expressing the velocity of flow through such an orifice is $v = \sqrt{2gh}$; multiplying both members of this equation by A, and substituting for the first member Av, its value q, we have, after transposing and correcting for *vena contracta*, $A = \frac{q}{.62\sqrt{2gh}}$, in which .62 is the coefficient for the *vena contracta* of the flow. Reducing this to cubic feet per minute and inches of water gauge represented by i, we have, finally, the equation $A = .0004 \times \frac{q}{\sqrt{i}}$. By this formula, Murgue has suggested assimilating the flow of air through a mine to the flow of a fluid through a thin plate; since, in each case, the quantity and the head or pressure vary in the same ratio. Thus, applying this formula to a mine, Murgue multiplies the ratio of the quantity of air passing (cubic feet per minute) and the square root of the water gauge (inches) by .0004, and obtains an area A, which he calls the equivalent orifice of the mine.

Potential Factor of a Mine. (*Proposed by J. T. Beard.*)—Equations 8 and 27,

pages 370–371, give, respectively, the pressure and the power that will circulate a given quantity of air per minute in a given airway. These equations may be written as equal ratios, expressed in factors of the current and the airway, respectively; thus, $\frac{p}{q^2} = \frac{ks}{a^3}$, and $\frac{u}{q^3} = \frac{ks}{a^3}$, which show that the ratio between the *pressure* and the square of the quantity *it* circulates in any given airway is equal to the ratio between the *power* and the cube of the quantity *it* circulates. Solving each of these equations with respect to q, we have the following:

With respect to pressure,

$$q = \left(a\sqrt{\frac{a}{ks}}\right)\sqrt{p}.$$

With respect to power,

$$q = \left(\frac{a}{\sqrt[3]{ks}}\right)\sqrt[3]{u}.$$

Hence, we observe that, in any airway, *for a constant pressure*, the quantity of air in circulation is proportional to the expression $a\sqrt{\frac{a}{ks}}$; and, *for a constant power*, the quantity is proportional to the expression $\frac{a}{\sqrt[3]{ks}}$, which terms are called the *potentials* of the mine with respect to pressure and power, respectively; and their values $\frac{q}{\sqrt{p}}$ and $\frac{q}{\sqrt[3]{u}}$ are the potentials of the current with respect to pressure and power, respectively. These factors, it will be observed, evaluate the airway, as they determine the quantity of air a given pressure or power will circulate in that airway (cubic feet per minute). By their use, the relative quantities of air any given pressure or power will circulate in different airways are readily determined. The rule may be stated as follows:

Rule.—*For any given pressure or power, the quantity of air in circulation is always proportional to the potential for pressure, or the potential for power, as the case may be.*

This rule finds important application in splitting (see Calculation of Natural Splitting). In all cases where the potential is used as a ratio, the *relative potential* may be employed by omitting the factor k; or it may be employed to obtain the pressure and power, in several splits by multiplying the final result by k (see Formulas 46, 47, etc., page 378).

Example.— 20,000 cu. ft. of air is passing in a mine in which the airway is 6 ft. × 8 ft., and 10,000 ft. long, under a certain pressure; it is required to find what quantity of air this same pressure will circulate in a mine in which the airway is 6 ft. × 12 ft., and 8,000 ft. long.

Calculating the potential X_p with respect to the pressure for each of these mines, or airways, we have, using the relative potential, $X_1 = 6 \times 8\sqrt{\frac{6 \times 8}{2(6+8) \times 10{,}000}} = .62845$, and $X_2 = 6 \times 12\sqrt{\frac{6 \times 12}{2(6+12) \times 8{,}000}} = 1.1384$. Since the ratio of the quantities is equal to the ratio of the potentials with respect to pressure, in these two mines, we write the proportion $20{,}000 : q_2 :: .62845 : 1.1384$, and $q_2 = \frac{20{,}000 \times 1.1384}{.62845} = 36{,}229$ cu. ft. per min.

Example.— 20,000 cu. ft. of air is passing in a mine in which the airway is 6 ft. × 8 ft., and 10,000 ft. long, under a certain power; it is required to find what quantity of air will be circulated by this same power in a mine in which the airway is 6 ft. × 12 ft., and 8,000 ft. long.

We calculate the potential X_u with respect to power for each of these mines, using, as before, the relative potential. Thus, $X_1 = \frac{6 \times 8}{\sqrt[3]{2(6+8) \times 10{,}000}} = .7337$, and $X_2 = \frac{6 \times 12}{\sqrt[3]{2(6+12) \times 8{,}000}} = 1.0905$. Then, in this case, since the ratio of the quantities is equal to the ratio of the potentials with

respect to power, we write the proportion, $20{,}000 : q_2 :: .7337 : 1.0905$, and $q_2 = \frac{20{,}000 \times 1.0905}{.7337} = 29{,}726$ cu. ft. per min.

The following table will serve to illustrate the use of the formulas employed in these calculations. It will be observed that there are several formulas for quantity, and for velocity, and for work or horsepower, but in each respective case the several formulas are derived by simple transposition of the terms of the original formula, and are tabulated here for convenience. Choice must be made in the use of any of these formulas, according to the known terms in each example. Thus, an example may ask: What pressure will be produced in passing a given quantity of air through a certain mine, the size and length of the airways being given? We then use the formula $p = \frac{k s q^2}{a^3}$. But if the question asks what quantity of air a given pressure will produce in this same mine, we use the formula $q = \sqrt{\frac{p a}{k s}} \times a$. It will be observed that this second formula is a simple transposition of the first.

In like manner the question may be asked, what power will produce a certain quantity of air in a certain airway; and the expression used, in this case, is $u = \frac{k s q^3}{a^3}$. Or, the question may be asked, what quantity of air will be produced in a given airway by means of a certain power or work applied to the airway. In this case, the formula used is $q = a\sqrt[3]{\frac{u}{k s}}$. If the question asks for the power required to produce a given velocity in a given airway, the formula employed is $u = k s v^3$. All of these formulas are derived by combining the simple formulas $p = \frac{k s v^2}{a}$, $q = a v$, and $u = q p$.

To illustrate the use of the formulas, we take as an example an underground road, 5 ft. wide by 4 ft. high, and 2,000 ft. in length, and calculate the value of each symbol or letter, assuming a velocity of 500 ft. per minute.

	Symbol.	Value of Symbol for this Particular Example.
Area of airway (5 ft. × 4 ft.)	a	20 sq. ft.
Horsepower *	h	2.959 H. P.
Coefficient of friction †	k	.0000000217 lb.
Length of airway	l	2,000 ft.
Perimeter of airway, 2(5 ft. + 4 ft.)	o	18 ft.
Pressure (lb. per sq. ft.)	p	9.765 lb.
Quantity of air (cu. ft. per min.)	q	10,000 cu. ft.
Area of rubbing surface	s	36,000 sq. ft.
Units of work per minute (power)	u	97,650 ft.-lb.
Velocity (ft. per min.)	v	500 ft.
Water gauge	i	1.87788 in.
Equivalent orifice of the mine	A	2.919 sq. ft.
Potential for power	X_u	217.16 units.
Potential for pressure	X_p	3,200 units.
Weight of 1 cu. ft. of downcast air	w	.08098 lb.
Motive column (downcast air)	M	120.5 ft.
Depth of furnace shaft	D	306.77 ft.
Average temperature of the upcast column	T	350° F.
Average temperature of the downcast column	t	32° F.

* A horsepower is equal to 33,000 units of work.

† This coefficient of friction is an invariable quantity, and is the same in every calculation relating to the friction of air in mines.

NOTE.—The water gauge is calculated to five decimal places to enable all the other values to be accurately arrived at. In practice, it is only read to one decimal place.

FORMULAS.

On the right side of each formula, the various calculations, based on the example given, are worked out in figures.

To Find:	No.	Formula.	Specimen Calculation.
Rubbing surface of an airway. (Sq. ft.)	1	$s = l\,o$	$2{,}000 \times 18 = 36{,}000$ sq. ft.
Area of an airway. (Sq.ft.)	2	$a = \frac{q}{v}$	$\frac{10{,}000}{500} = 20$ sq. ft. of area.
Velocity. (Ft. per min.)	3	$v = \frac{q}{a}$	$\frac{10{,}000}{20} = 500$ ft.
	4	$v = \sqrt[3]{\frac{u}{k\,s}}$	$\sqrt[3]{\frac{97{,}650}{.0000000217 \times 36{,}000}} = 500$ ft.
	5	$v = \sqrt{\frac{p\,a}{k\,s}}$	$\sqrt{\frac{9.765 \times 20}{.0000000217 \times 36{,}000}} = 500$ ft.
	6	$v = \frac{u}{p\,a}$	$\frac{97{,}650}{9.765 \times 20} = 500$ ft.
Pressure. (Lb. per sq. ft.)	7	$p = \frac{k\,s\,v^2}{a}$	$\frac{.0000000217 \times 36{,}000 \times 500^2}{20} = 9.765$ lb.
	8	$p = \frac{k\,s\,q^2}{a^3}$	$\frac{.0000000217 \times 36{,}000 \times 10{,}000^2}{20^3} = 9.765$ lb.
	9	$p = \frac{u}{q}$	$\frac{97{,}650}{10{,}000} = 9.765$ lb.
	10	$p = M\,w$	$120.58 \times .08098 = 9.765$ lb.
	11	$p = 5.2\,i$	$5.2 \times 1.87788 = 9.765$ lb.
	12	$p = \frac{q^2}{X_u^{\,3}}$	$\frac{10{,}000^2}{217.16^3} = 9.765$ lb.
	13	$p = \frac{q^2}{X_p^{\,2}}$	$\left(\frac{10{,}000}{3{,}200}\right)^2 = 9.765$ lb.
Water gauge. (Inches.)	14	$i = \frac{p}{5.2}$	$\frac{9.765}{5.2} = 1.87788$ in.
Resistance of an airway. (Total pressure, lb.)	15	$p\,a = k\,s\,v^2$	$.0000000217 \times 36{,}000 \times 500^2 = 195.3$ lb.
	16	$p\,a = \frac{u}{v}$	$\frac{97{,}650}{500} = 195.3$ lb.

To Find:	No.	Formula.	Specimen Calculation.
Quantity. (Cu.ft.per min)	17	$q = a\,v$	$20 \times 500 = 10{,}000$ cu. ft.
	18	$q = \frac{u}{p}$	$\frac{97{,}650}{9.765} = 10{,}000$ cu. ft.
	19	$q = \sqrt{\frac{p\,a}{k\,s}} \times a$	$\sqrt{\frac{9.765 \times 20}{.0000000217 \times 36{,}000}} \times 20 = 10{,}000$ cu. ft.
	20	$q = \sqrt[3]{\frac{u}{k\,s}} \times a$	$\sqrt[3]{\frac{97{,}650}{.0000000217 \times 36{,}000}} \times 20 = 10{,}000$ cu. ft.
	21	$q = X_u \sqrt[3]{u}$	$217.16 \times \sqrt[3]{97{,}650} = 10{,}000$ cu. ft.
	22	$q = \sqrt[3]{X_p^2\,u}$	$\sqrt[3]{3{,}200^2 \times 97{,}650} = 10{,}000$ cu. ft.
	23	$q = X_p \sqrt{p}$	$3{,}200 \times \sqrt{9.765} = 10{,}000$ cu. ft.
Units of work per minute, or power on the air. (Ft.-lb.per min)	24	$u = a\,v\,p$	$20 \times 500 \times 9.765 = 97{,}650$ ft.-lb.
	25	$u = q\,p$	$10{,}000 \times 9.765 = 97{,}650$ ft.-lb.
	26	$u = k\,s\,v^3$	$.0000000217 \times 36{,}000 \times 500^3 = 97{,}650$ ft.-lb.
	27	$u = \frac{k\,s\,q^3}{a^3}$	$\frac{.0000000217 \times 36{,}000 \times 10{,}000^3}{20^3} = 97{,}650$ ft.-lb.
	28	$u = h\,33{,}000$	$2.959 \times 33{,}000 = 97{,}650$ ft.-lb.
	29	$u = \frac{q^3}{X_u^3}$	$\frac{10{,}000^3}{217.16^3} = 97{,}650$ ft.-lb.
	30	$u = \frac{q^3}{X_p^2}$	$\frac{10{,}000^3}{3{,}200^2} = 97{,}650$ ft.-lb.
Horsepower.	31	$h = \frac{u}{33{,}000}$	$\frac{97{,}650}{33{,}000} = 2.959$ H. P.
Power potential. (Units.)	32	$X_u = \frac{a}{\sqrt[3]{k\,s}}$	$\frac{20}{\sqrt[3]{.0000000217 \times 36{,}000}} = 217.16$ units.
	33	$X_u = \sqrt[3]{\frac{q^2}{p}}$	$\sqrt[3]{\frac{10{,}000^2}{9.765}} = 217.16$ units.
	34	$X_u = \frac{q}{\sqrt[3]{u}}$	$\frac{10{,}000}{\sqrt[3]{97{,}650}} = 217.16$ units.

To Find:	No.	Formula.	Specimen Calculation.
Pressure potential. (Units.)	35	$X_p = a\sqrt{\frac{a}{k\,s}}$	$20\sqrt{\frac{20}{.0000000217 \times 36{,}000}} = 3{,}200$ units.
	36	$X_p = \frac{q}{\sqrt{p}}$	$\frac{10{,}000}{\sqrt{9.765}} = 3{,}200$ units.
Equivalent orifice. (Sq. ft.)	37	$A = \frac{.0004\,q}{\sqrt{i}}$	$\frac{.0004 \times 10{,}000}{\sqrt{1.87788}} = 2.919$ sq. ft.
Motivecolumn, downcast air. (Feet.)	38	$M = D \times \frac{T-t}{459+T}$	$306.77 \times \frac{350-32}{459+350} = 120.5$ ft.
	39	$M = \frac{p}{w}$	$\frac{9.765}{.08098} = 120.5$ ft.
Motivecolumn, upcast air. (Feet.)	40	$M = D \times \frac{T-t}{459+t}$	$306.77 \times \frac{350-32}{459+32} = 198.7$ ft.
	39	$M = \frac{p}{w}$	$\frac{9.765}{.04915} = 198.7$ ft.

Variation of the Elements.—In the illustration of the foregoing table, we have assumed fixed conditions of motive column, as well as fixed conditions in the mine airways. It is often convenient, however, to know how the different elements, as velocity v, quantity q, pressure p, power u, etc., will vary in different circulations; since we may, by this means, compare the circulations in *different* airways, or the results obtained by applying different pressures and powers to the *same* airway. These laws of variation must always be applied with great care. For example, before we can ascertain how the quantity in circulation will vary in different airways, we must know whether the *pressure* or the *power* is constant or the same for each airway. The following rules may always be applied:

For a constant pressure: v varies as $\sqrt{\frac{a}{lo}}$; q varies as $a\sqrt{\frac{a}{lo}}$ (relative potential for pressure).

For a constant power: v varies as $\frac{1}{\sqrt[3]{lo}}$; q varies as $\frac{a}{\sqrt[3]{lo}}$ (relative potential for power).

For a constant velocity: q varies as a; p varies as $\frac{lo}{a}$; u varies as lo.

For a constant quantity: v varies *inversely* as a; p varies *inversely* as X_u^3 (potential for power); u varies *inversely* as X_u^3 (potential for power) or directly as p.

For the same airway: The following terms vary as each other: v, q, $\sqrt{p}$, $\sqrt[3]{u}$.

SIMILAR AIRWAYS.

r = length of similar side, or similar dimension.

For a constant pressure: v varies as $\sqrt{\frac{r}{l}}$; q varies as $r^2 \times \sqrt{\frac{r}{l}}$; r varies as lv^2, or $\sqrt[5]{lq^2}$.

For a constant power: v varies as $\frac{1}{\sqrt[3]{lr}}$; q varies as $r \times \sqrt[3]{\frac{r^2}{l}}$; r varies as $\frac{1}{l\,v^3}$, or $\sqrt[5]{l\,q^3}$.

For a constant velocity: q varies as r^2; p varies as $\frac{l}{r}$; u varies as lr; r varies as $\sqrt{q}$, $\frac{l}{p}$, or $\frac{u}{l}$.

For a constant quantity: v varies *inversely* as r^2; p and u vary *inversely* as $\frac{r^5}{l}$; r varies as $\frac{1}{\sqrt{v}}$, $\sqrt[5]{\frac{l}{p}}$, or $\sqrt[5]{\frac{l}{u}}$.

Furnace Ventilation.

p (motive column) varies as D; q varies as $\sqrt{D}$.

Fan Ventilation.

It has been customary in calculations pertaining to the yield of centrifugal ventilators to assume as follows: q varies as n; p varies as n^2; u varies as n^3.

More recent investigation, however, shows that when we double the speed we do not obtain double the quantity of air in circulation; or, in other words, the quantity does not vary exactly as the number of revolutions of the fan. Investigation also points to the fact that the efficiency of centrifugal ventilators *decreases* as the speed *increases*. To what extent this is the case has not been thoroughly established. The variation between the speed of a fan and the quantity, pressure, power, and efficiency, as calculated from a large number of reliable fan tests, may be stated as follows:

For the same fan, discharging against a *constant* potential: q varies as $n^{.97}$. p varies as $n^{1.94}$. *Complement of efficiency* $(1 - K)$ varies as $n^{.425}$.

The efficiency here referred to is the *mechanical efficiency*, or the ratio between the effective work qp and the theoretical work of the fan.

DISTRIBUTION OF AIR IN MINE VENTILATION.

When a mine is first opened, the air is conducted in a single current around the face of all the headings and workings, and returns again to the upcast shaft, where it is discharged into the atmosphere. As the development of the mine advances, however, it becomes necessary to divide the air into two or more splits or currents. This division or splitting of the air-current is usually accomplished at the foot of the downcast, or as soon as possible after the current enters the mine. There are several reasons why the air-current should be thus divided. The most important reason is that the mine is thereby divided into separate districts, each of which has its own ventilating current, which may be increased or decreased at will. Fresh air is thus obtained at the face of the workings, and the ventilation is under more perfect control. It often happens that certain portions of a mine are more gaseous than others, and it is necessary to increase the volume of air in these portions, which can be readily accomplished when each district has its own separate circulation. Again, the gases and foul air are not conducted from one district to another, but each district is supplied with fresh air direct from the main intake. Should an explosion occur in any part of the mine, it is more apt to be confined to one locality when a mine is thus divided into separate districts. Another consideration is the reduced power necessary to accomplish the same circulation in the mine; or the increased circulation obtained by the use of the same power.

Requirements of Law in Regard to Splitting.—The Anthracite Mine Law of Pennsylvania specifies that every mine employing more than 75 persons must be divided into two or more ventilating districts, thus limiting the number that are allowed to work on one air-current to 75 persons. The Bituminous Mine Law of Pennsylvania limits the number allowed to work upon one current to 65 persons, except in special cases, where this number may be increased to 100 persons at the discretion of the mine inspector.

Practical Splitting of the Air-Current.—When the air-current is divided into two or more branches, it is said to be *split*. The current may be divided one or more times; when split or divided once, the current is said to be traveling

in *two splits*, each branch being termed a split. The number of splits in which a current is made to travel is understood as the number of separate currents in the mine, and not as the number of *divisions* of the current.

Primary Splits.—When the main air-current is divided into two or more splits, each of these is called a *primary split.*

Secondary Splits.—Secondary splits are the divisions of a primary split.

Tertiary Splits.—Tertiary splits result from the division of a secondary split.

Equal Splits of Air.—When a mine is spoken of as having two or more *equal splits*, it is understood to mean that the length and the size of the separate airways forming those splits are equal in each case. It follows, of course, from this that the ventilating current traveling in each split will be the same, inasmuch as they are all subject to the same ventilating pressure. When an equal circulation is obtained in two or more splits by the use of regulators, these splits cannot be spoken of as equal splits.

Unequal Splits of Air.—By this is meant that the airways forming the splits are of unequal size or length. Under this head we will consider (*a*) *Natural Division of the Air-Current;* (*b*) *Proportionate Division of the Air-Current.*

Natural Division of the Air-Current.—By *natural division of air* is meant any division of the air that is accomplished without the use of regulators; or, in other words, such division of the air-current as results from natural means. If the main air-current at any given point in a mine is free to traverse two separate airways in passing to the foot of the upcast shaft, and each of these airways is free or an open split, i. e., contains no regulator, the division of the air will be a *natural division.* In such a case, the larger quantity of air will always traverse the shorter split of airway. In other words, an air-current always seeks the shortest way out of a mine. A comparatively small current, however, will always traverse the long split or airway.

Calculation of Natural Splitting.—It is always assumed, in the calculation of the splitting of air-currents, that the pressure at the mouth of each split, starting from any given point, is the same. Since this is the case, in order to find the quantity of air passing in each of several splits starting from a common point, the rule given under Potential Factor of a Mine is applied. This rule may be stated as follows:

The ratio between the quantity of air passing in any split and the pressure potential of that split is the same for all splits starting from a common point. Also, the ratio between the entire quantity of air in circulation in the several splits and the sum of the pressure potentials of those splits is the same as the above ratio, and is equal to the square root of the pressure.

Expressed as a formula, indicating the sum of the pressure potentials ($X_1 + X_2 +$ etc.) by the expression ΣX_p, this rule is $\frac{Q}{\Sigma X_p} = \frac{q_1}{X_1} = \sqrt{p}$. Hence, $p = \frac{Q^2}{(\Sigma X_p)^2}$ and $u = \frac{Q^3}{(\Sigma X_p)^2}$ express the pressure and power, respectively, absorbed by the circulation of the splits. These are the basal formulas for splitting, from which any of the factors may be calculated by transposition. They will be found illustrated in the table at the end of this section. We will give here two examples only, showing the calculation of the natural division of an air-current between several splits. We have, from the above formulas, $q_1 = \frac{X_1}{\Sigma X_p} Q$.

EXAMPLE.—In a certain mine, an air-current of 60,000 cu. ft. per minute is traveling in two splits as follows: Split A, 6 ft. × 8 ft., 5,000 ft. long; split B, 5 ft. × 8 ft., 10,000 ft. long. It is required to find the natural division of this air-current.

Calculating the relative potentials for pressure in each split, we have

$$\left.\begin{aligned} &\text{for split } A,\ X_1 = 48\sqrt{\frac{48}{2(6+8)5{,}000}} = .8888 \\ &\text{for split } B,\ X_2 = 40\sqrt{\frac{40}{2(5+8)10{,}000}} = .4961 \end{aligned}\right\} \text{ and } \Sigma X_p = 1.3849;$$

and substituting these values, we have,

$$q_1 = \frac{.8888}{1.3849} \times 60{,}000 = 38{,}506 \text{ cu. ft. per min.};$$

and $$q_2 = \frac{.4961}{1.3849} \times 60{,}000 = 21{,}494 \text{ cu. ft. per min.}$$

Example.—In a certain mine, there is an air-current of 100,000 cu. ft. per minute traveling in three splits as follows: Split A, 6 ft. $\times$ 10 ft., 8,000 ft. long; split B, 6 ft. $\times$ 12 ft., 15,000 ft. long; split C, 5 ft. $\times$ 10 ft., 6,000 ft. long. Find the natural division of this current of air.

Calculating the respective relative potentials with respect to pressure, we have

$$\text{for split } A,\ X_1 = 60\sqrt{\frac{60}{2(6+10)\times 8{,}000}} = .9185;$$

$$\text{for split } B,\ X_2 = 72\sqrt{\frac{72}{2(6+12)\times 15{,}000}} = .8314;$$

$$\text{for split } C,\ X_3 = 50\sqrt{\frac{50}{2(5+10)\times 6{,}000}} = .8333.$$

Adding these potentials, we have $\Sigma X_p = .9185 + .8314 + .8333 = 2.5832$. Then, applying the foregoing rule, we have

$$q_1 = \frac{.9185}{2.5832}\times 100{,}000 = 35{,}556 \text{ cu. ft. per min.};$$

$$q_2 = \frac{.8314}{2.5832}\times 100{,}000 = 32{,}184 \text{ cu. ft. per min.};$$

and

$$q_3 = \frac{.8333}{2.5832}\times 100{,}000 = 32{,}260 \text{ cu. ft. per min.}$$

$$\text{Total,} \qquad \overline{100{,}000}$$

Proportional Division of the Air-Current.—It continually happens that different proportions of air are required in the several splits of a mine than would be obtained by the natural division of the air-current. It is usually the case that the longer splits employ a larger number of men, and require a larger quantity of air passing through them. They, moreover, liberate a larger quantity of mine gases, for which they require a larger quantity of air than is passing in the smaller splits. The natural division of the air-current would give to these longer splits *less* air, and to the shorter ones a *larger* amount of air, which is directly the reverse of what is needed. On this account, recourse must be had to some means of dividing this air proportionately, as required. This is accomplished by the use of regulators, of which there are two general types, the *box regulator* and the *door regulator*.

Box Regulator.—This is simply an obstruction placed in those airways that would naturally take more air than the amount required. It consists of a brattice or door placed in the entry, and having a small shutter that can be opened to a greater or less amount. The shutter is so arranged as to allow the passage of more or less air, according to the requirements. The box regulator is, as a rule, placed at the end or near the end of the return airway of a split. It is usually placed at this point as a matter of convenience, because, in this position, it obstructs the roads to a less extent, the haulage from the back entry in this split being carried over to the main haulway, through a cross-cut, before this point is reached. The difficulty, however, can be avoided, in most cases, by proper consideration in the planning of the mine with respect to haulage and ventilation. The objection to this form of regulator is that, in effect, it lengthens the airway, or increases its resistance, making the resistance of all the airways, per foot of area, the same. It is readily observed that, by thus increasing the resistance of the mine, the horsepower of the ventilation is largely increased, for the same circulation. This is an important point, as it will be found that the power required for ventilation is thus increased anywhere from 50% to 100% over the power required when the other form of regulator can be adopted.

Door Regulator.—In this form of regulator, which was first introduced by Beard, the division of the air is made at the mouth of the split. The regulator consists of a door hung from a point of the rib between two entries, and swung into the current so as to cut the air like a knife. The door is provided with a set lock, so that it may be secured in any position, to give more or less air to the one or the other of the splits, as required. The position of this regulator door, as well as the position of the shutter in the box regulator, is always ascertained practically by trial. The door is set so as to divide the area of the airway proportionate to the work absorbed in the

respective splits. The pressure in any split is not increased, each split retaining its natural pressure.

Calculation of Pressure for Box Regulators.—When any required division of the air-current is to be obtained by the use of box regulators, these are placed in all the splits, save one. This split is called the *open*, or *free, split*, and its pressure is calculated in the usual way by the formula $p = \frac{ksq^2}{a^3}$. The natural pressure in this open split determines the pressure of the entire mine, since all the splits are subject to the same pressure in this form of splitting.

First, determine in which splits regulators will have to be placed, in order to accomplish the required division of the air. Calculate the natural pressure, or pressure due to the circulation of the air-current, for each split, when passing its required amount of air, using the formula $p = \frac{ksq^2}{a^3}$. The split showing the greatest natural pressure is taken as the free split. In each of the other splits, box regulators must be placed, to increase the pressure in those splits; or, in other words, to increase the resistance of those splits per unit of area.

EXAMPLE.—The ventilation required in a certain mine is:

split A, 6 ft. × 9 ft., 8,000 ft. long; 40,000 cu. ft. per min.
split B, 5 ft. × 8 ft., 6,000 ft. long; 40,000 cu. ft. per min.
split C, 9 ft. × 9 ft., 8,000 ft. long; 10,000 cu. ft. per min.
split D, 6 ft. × 8 ft., 10,000 ft. long; 30,000 cu. ft. per min.

In which of these splits should regulators be placed, to accomplish the required division of air, and what will be the mine pressure?

Calculating the pressure due to friction in each split when passing its required amount of air, we find,

$$\text{for split } A,\ p = \frac{.0000000217 \times 2(6+9)8{,}000 \times 40{,}000^2}{54^3} = 52.92 \text{ lb. per sq. ft.;}$$

$$\text{for split } B,\ p = \frac{.0000000217 \times 2(5+8)6{,}000 \times 40{,}000^2}{40^3} = 84.63 \text{ lb. per sq. ft.;}$$

$$\text{for split } C,\ p = \frac{.0000000217 \times 2(9+9)8{,}000 \times 10{,}000^2}{81^3} = 1.176 \text{ lb. per sq. ft.;}$$

$$\text{for split } D,\ p = \frac{.0000000217 \times 2(6+8)10{,}000 \times 30{,}000^2}{48^3} = 49.45 \text{ lb. per sq. ft.}$$

Split B has the greatest pressure, and is therefore the free split. Box regulators are placed in each of the other splits to increase their respective pressures to the pressure of the free split or the mine pressure. Therefore, the mine pressure in this circulation is 84.63 lb. per sq. ft.

The Size of opening in a box regulator is calculated by the formula for determining the flow of air through an orifice in a thin plate under a certain head or pressure. The difference in pressure between the two sides of a box regulator is the pressure establishing the flow through the opening, which corresponds to the head h in the formula $v = \sqrt{2gh}$. This regulator is usually placed at the end of a split or airway, and since the regulator increases the pressure in the lesser split so as to make it equal to the pressure in the other split, the pressure due to the regulator will be equal to the ventilating pressure at the mouth of the split, less the *natural* pressure or the pressure due to friction in this split. Hence, when the position of the regulator is at the end of the split, the pressure due to friction in the split is first calculated by the formula $p = \frac{ksq^2}{a^3}$, and this pressure is deducted from the ventilating pressure of the free or open split, which gives the pressure due to the regulator. This is then reduced to inches of water gauge, and substituted for i in the formula $A = \frac{.0004q}{\sqrt{i}}$. The value of A thus obtained is the area (square feet) of the opening in the regulator.

EXAMPLE.— 50,000 cu. ft. of air is passing per minute in a certain mine, in two equal splits, under a pressure equal to 2 in. of water gauge, and it is required to reduce the quantity of air passing in one of these splits, by a box regulator placed at the end of the split, so as to pass but 15,000 cu. ft. per

minute in this split. Find the area of the opening in the regulator, assuming that the ventilating power is decreased to maintain the pressure constant at the mouth of the splits after placing the regulator. The size and length of each split is 6 ft. × 10 ft. and 10,000 ft. long.

The natural pressure for the split in which the regulator is placed will be

$$p = \frac{k s q^2}{a^3} = \frac{.0000000217 \times 2(6+10) \times 10{,}000 \times 15{,}000^2}{(6 \times 10)^3} = 7.233 \text{ lb. per sq. ft.}$$

Then, $\frac{7.233}{5.2} = 1.4$ in. of water gauge (nearly), due to friction of the air-current in this split. And, $2 - 1.4 = .6$ in. water gauge due to regulator.

Finally, $A = \frac{.0004 q}{\sqrt{.6}} = \frac{.0004 \times 15{,}000}{\sqrt{.6}} = 7.746$ sq. ft., area of opening.

Size of Opening for a Door Regulator.—The sectional area at the regulator is divided proportionately to the work to be performed in the respective splits according to the proportion $A_1 : A_2 :: u_1 : u_2$. Or since $A_1 + A_2 = a$, we have $A_1 : a :: u_1 : u_1 + u_2$, and $A_1 = \frac{u_1}{u_1 + u_2} \times a$. This furnishes a method of proportionate splitting in which each split is ventilated under its own natural pressure. The same result would be obtained by the placing of the box regulator at the intake of any split, thereby regulating the amount of air passing into that split, but the door regulator presents less resistance to the flow of the air-current. The practical difference between these two forms of regulators is that in the use of the box regulator each split is ventilated under a pressure equal to the natural pressure of the open or free split, which very largely increases the horsepower required for the ventilation of the mine; while in the use of the door regulator each split is ventilated under its own natural pressure, and the proportionate division of the air is accomplished without any increase of horsepower. This is more clearly explained in the two following paragraphs, and the table showing the comparative horsepowers of the two methods.

Calculation of Horsepower for Box Regulators.—By the use of the box regulator, the pressure in all the splits is made equal to the greatest *natural* pressure in any one. This split is made the open or free split, and its natural pressure becomes the pressure for all the splits, or the *mine* pressure. This mine pressure, multiplied by the total quantity of air in circulation (the sum of the quantities passing in the several splits), and divided by 33,000, gives the horsepower upon the air, or the horsepower of the circulation. Thus, in the first example given on page 376, in which for split B the pressure $p = 84.63$ lb. per sq. ft. and the total quantity of air passing per minute is 120,000 cu. ft., we have

$$h = \frac{84.63 \times 120{,}000}{33{,}000} = 307.745 \text{ H. P.}$$

Calculation of Horsepower for Door Regulators.—In the use of the door regulator, each split is ventilated under its own natural pressure, and, hence, in the calculation of the horsepower of such a circulation, the power of each split must be calculated separately, and the sum of these several powers will be the entire power of the circulation. For the purpose of comparison, we tabulate below the results obtained in the application of these two methods of dividing the air in the above example.

Splits.	Natural Division.	Required Division.	Horsepower. Door Regulator.	Horsepower. Box Regulator.
Split A, 6 ft. × 9 ft., 8,000 ft. long	28,277	40,000	64.145	102.582
Split B, 5 ft. × 8 ft., 6,000 ft. long	22,360	40,000	102.582	102.582
Split C, 9 ft. × 9 ft., 8,000 ft. long	47,423	10,000	.356	25.645
Split D, 6 ft. × 8 ft., 10,000 ft. long	21,940	30,000	44.955	76.936
Totals	120,000	120,000	212.038	307.745

SPLITTING FORMULAS

The following table of formulas will serve to illustrate the methods of calculation in splitting. The example assumes the same airway as that given on page 369 and used to illustrate the table of formulas, page 370, but the air-current is divided, as specified in the table:

NATURAL DIVISION.

Primary Splits.—Split (1) = 4 ft. × 5 ft., 800 ft. long. Split (2) = 4 ft. × 5 ft., 1,200 ft. long.

To Find:	No.	Formula.	Specimen Calculation.
Potential for pressure.	35	$X_p = a\sqrt{\frac{a}{ks}}$.	(1) $20\sqrt{\frac{20}{.0000000217 \times 14,400}} = 5,060.$ (2) $20\sqrt{\frac{20}{.0000000217 \times 21,600}} = 4,131.$
		$\Sigma X_p = (X_1 + X_2 + \text{etc.})$.	$5,060 + 4,131 = 9191.$
Natural division.	41	$q = \frac{X_p}{\Sigma X_p} \times Q.$	(1) $\frac{5,060}{9,191} \times 10,000 = 5,505$ cu. ft. (2) $\frac{4,131}{9,191} \times 10,000 = 4,495$ cu. ft.

Or the natural division may be calculated from the pressure at the mouth of the several splits by using formula (23); thus,

	23	$q = X_p\sqrt{p}.$	(1) $5,060\sqrt{1.1838} = 5,505$ cu. ft. (2) $4,131\sqrt{1.1838} = 4,495$ cu. ft. See formula (42).
Pressure.	42	$p = \frac{Q^2}{(\Sigma X_p)^2}.$	$\frac{10,000^2}{9,191^2} = 1.1838$ lb.
Power.	43	$u = \frac{Q^3}{(\Sigma X_p)^2}.$	$\frac{10,000^3}{9,191^2} = 11,838$ units.
Quantity.	44	$Q = \Sigma X_p\sqrt{p}.$	$9,191\sqrt{1.1838} = 10,000$ cu. ft.
	45	$Q = \sqrt[3]{(\Sigma X_p)^2 u}.$	$\sqrt[3]{9,191^2 \times 11,838} = 10,000$ cu. ft.
Increase of quantity due to splitting. (Pressure constant.)	46	$Q = \frac{\Sigma X_p}{X_{p-o}} \times q_o.$	$\frac{9,191}{3,200} \times 10,000 = 28,722$ cu. ft.
Increase in quantity due to splitting. (Power constant.)	47	$Q = q\sqrt[3]{\left(\frac{\Sigma X_p}{X_{p-o}}\right)^2}.$	$10,000\sqrt[3]{\left(\frac{9,191}{3,200}\right)^2} = 20,205$ cu. ft.

Secondary Splits.—(1) 4 ft. × 5 ft., 800 ft. long. (2) 4 ft. × 5ft., 500 ft. long. (3) 4 ft. × 5 ft., 400 ft. long. (4) 4 ft. × 5 ft., 300 ft. long.

The calculation is often shortened, when many splits are concerned, by using the *relative potential*, omitting the factor k; but the final result must then be multiplied by k to obtain the pressure or power; or, these factors must be divided by k, when finding the quantity, as in formulas (49) to (51).

To Find:	No.	Formula.	Specimen Calculation.
Relative potential for pressure.	35	$X_p = a\sqrt{\frac{a}{s}}.$	(1) $20\sqrt{\frac{20}{14,400}} = .7471.$ (2) $20\sqrt{\frac{20}{9,000}} = .9428.$ (3) $20\sqrt{\frac{20}{7,200}} = 1.0541.$ (4) $20\sqrt{\frac{20}{5,400}} = 1.2172.$
Natural division.	48	$q_1 = Q - q_2.$ $q_2 = \frac{Q}{1 + X_1\sqrt{\frac{1}{X_2^2} + \frac{1}{(X_3 + X_4)^2}}}.$	(1) $10,000 - 5,388 = 4,612$ cu. ft. See formula (48). (2) $\frac{10,000}{1 + .7471\sqrt{\frac{1}{9,428^2} + \frac{1}{(1.0541 + 1.2172)^2}}} = 5,388$ cu. ft.
	41	$q = \frac{X_p}{\Sigma X_p} \times Q.$	(3) $\frac{1.0541}{(1.0541 + 1.2172)} \times 5,388 = 2,500$ cu. ft. (4) $\frac{1.2172}{(1.0541 + 1.2172)} \times 5,388 = 2,888$ cu. ft.
Pressure.	49	$p = k\left(\frac{Q}{X_1 + \frac{1}{\sqrt{\frac{1}{X_2^2} + \frac{1}{(X_3 + X_4)^2}}}}\right)^2.$	$.0000000217\left(\frac{10,000}{.7471 + \frac{1}{\sqrt{\frac{1}{.9428^2} + \frac{1}{(1.0541 + 1.2172)^2}}}}\right)^2 = .8290$ lb.
Power.	50	$u = k\frac{Q^3}{\left(X_1 + \frac{1}{\sqrt{\frac{1}{X_2^2} + \frac{1}{(X_3 + X_4)^2}}}\right)^2}.$	$.0000000217\frac{10,000^3}{\left(.7471 + \frac{1}{\sqrt{\frac{1}{.9428^2} + \frac{1}{(1.0541 + 1.2172)^2}}}\right)^2} = 8,290$ units.
Quantity.	51	$Q = \left(X_1 + \frac{1}{\sqrt{\frac{1}{X_2^2} + \frac{1}{(X_3 + X_4)^2}}}\right)\sqrt{\frac{p}{k}}.$	$\left(.7471 + \frac{1}{\sqrt{\frac{1}{.9428^2} + \frac{1}{(1.0541 + 1.2172)^2}}}\right) \times \sqrt{\frac{.829}{.0000000217}} = 10,000$ cu. ft.

PROPORTIONATE DIVISION.

Primary Splits (only).—(1) 4 ft. × 5 ft., 800 ft. long = 3,500 cu. ft. (2) 4 ft. × 5 ft., 1,200 ft. long = 6,500 cu. ft.

To Find:	No.	Formula.	Specimen Calculation.
Pressure due to friction.	13	$p = \frac{q^2}{X_p^2}$.	(1) $\frac{3,500^2}{5,060^2} = .47845$ lb. (2) $\frac{6,500^2}{4,131^2} = 2.4757$ lb.

To accomplish this division of air, the pressure in split (1) must be increased by means of a regulator to make it equal to the pressure in the free or open split (2), and, hence, the pressure due to the regulator is equal to the difference between the natural pressures in these splits.

Pressure due to the regulator in split (1).	53	$p = p_2 - p_1$.	2.4757 — .47845 = 1.99725 lb.
Area of the opening in regulator.	37	$A = \frac{.0004\,q}{\sqrt{i}}$.	$\frac{.0004 \times 3,500}{\sqrt{\frac{1.99725}{5.2}}} = 2.259$ sq. ft.

Secondary Splits.—(1) 4 ft. × 5 ft., 800 ft. — 3,500 cu. ft. (2) 4 ft. × 5 ft., 500 ft. — 6,500 cu. ft. (3) 4 ft. × 5 ft., 400 ft. — 4,000 cu. ft. (4) 4 ft. × 5 ft., 300 ft. — 2,500 cu. ft.

NOTE—When using the relative potential, multiply the result by k, to obtain the pressure, or the power.

Pressure due to friction. Free split–secondary pressure.	13	$p = \left(\frac{q}{X_p}\right)^2$.	(1) $.0000000217\left(\frac{3,500}{.7471}\right)^2 = .47848$ lb. (2) $.0000000217\left(\frac{6,500}{.9428}\right)^2 = 1.0314$ lb. (3) $.0000000217\left(\frac{4,000}{1.0541}\right)^2 = .31248$ lb. (4) $.0000000217\left(\frac{2,500}{1.2172}\right)^2 = .091546$ lb.

Since the natural pressure in (3) is greater than that in (4), (3) is the free split, and its natural pressure is the pressure for the secondary splits. The pressure for the primary splits is then found by first adding the pressures in (2) and (3), and if their sum is greater than the natural pressure for (1), it becomes the pressure for the primary splits, or the mine pressure. If the natural pressure for (1) is the greater, this is made the free split, and *its* natural pressure becomes the primary or mine pressure. In this case, the secondary pressure must be increased by placing a regulator in split (3).

Primary or mine pressure.		$p_2 + p_3$.	1.0314 + .31248 = 1.34388.
Pressure due to the regulators.		$p_3 - p_4$. $(p_2 + p_3) - p_1$.	(4) .31248 — .091546 = .220934 lb. (1) (1.0314 + .31248) — .47848 = .86540 lb.
Areas of openings in the regulators.	37	$A = \frac{.0004\,q}{\sqrt{i}}$.	(4) $\frac{.0004 \times 2,500}{\sqrt{\frac{.220934}{5.2}}} = 4.8514$ sq. ft. (1) $\frac{.0004 \times 3,500}{\sqrt{\frac{.8654}{5.2}}} = 3.4328$ sq. ft.

METHODS AND APPLIANCES IN THE VENTILATION OF MINES.

Ascensional Ventilation.—Every mine, as far as practicable, should be ventilated upon the plan known as ascensional ventilation. This term refers particularly to the ventilation of inclined seams. The air should enter the mine at its lowest point, as nearly as possible, and from thence be conducted through the mine to the higher points, and there escape by a separate shaft, if such an arrangement is practicable. Where the seam is dipping considerably and is mined through a vertical shaft, the upcast shaft should be located as far to the rise of the downcast shaft as possible. The intake air is then first conducted to the lowest point of the dip workings, which it traverses upon its way to the higher workings. In the case of a slope working where a pair of entries is driven to the dip, one being used as the intake and the other the return, there being cross-entries or levels driven at regular intervals along the slope, the air should be conducted at once to the inside workings, from which point it returns, ventilating each pair of cross-entries from the inside, outwards. Where the development of the cross-entries or levels is considerable, their circulation is considered separately, and a fresh air split is made in the intake at each pair of levels. In all ventilation, the main point to be observed is to conduct the air-current first to the inside workings, from whence it is distributed along the working face as it returns toward the upcast.

General Arrangement of Mine Plan.—Every mine should be planned with respect to three main requirements, viz.: (a) *haulage;* (b) *drainage;* (c) *ventilation.* These requirements are so closely connected with one another that the consideration of one of them necessitates a reference to all. The mine should be planned so that the coal and the water will gravitate toward the opening, as far as possible. There are many reasons, in the consideration of non-gaseous mines, why the haulage should be effected upon the return airways. The haulage road is always a dusty road, caused by the traveling of men and mules, as well as by the loss of coal in transit, which becomes reduced to fine slack and powder. If the haulage is accomplished upon the intake entry or air-course, this dust is carried continually into the mine and working places, which should be avoided whenever possible. When the loaded cars move in the same direction as the return air, the ventilation of the mine is not as seriously impeded. It is often the case that fewer doors are required upon the return airway than upon the intake, which is a feature favorable to haulage roads. Again, in this arrangement, the hoisting shaft is made the upcast shaft, which prevents the formation of ice, and consequent delay in hoisting in the winter season. The arrangement, however, presupposes the use of the force fan or blower, since if a furnace or exhaust fan is employed, a door, or probably double doors, would have to be placed upon the main haulage road at the shaft bottom, which would be a great hindrance.

In the ventilation of gaseous mines, however, other and more important considerations demand attention. The gaseous character of the return current prevents making the return airway a haulageway. In such mines, the haulage should always be accomplished upon the intake air, as any other system would often result in serious consequences. In such gaseous mine, men and animals must be kept off the return airways as far as this is possible.

As far as practicable, ventilation should be accomplished in sections or districts, each district having its own split of air from the main intake, and its own return connecting with the main return of the mine. Reference has been made to this under Distribution of the Air in Mine Ventilation. This splitting of the air-current is accomplished preferably by means of an air bridge, either an under crossing or an over crossing. There are, in general, three systems of ventilation, with respect to the ventilating motor employed: (a) *natural ventilation;* (b) *furnace ventilation;* (c) *mechanical ventilation.*

Natural ventilation means such ventilation as is secured by natural means, or without the intervention of artificial appliances, such as the furnace, or any mechanical appliances by which the circulation of air is maintained. In natural ventilation, the ventilating motor or air motor is an air column that exists in the downcast shaft by virtue of the greater weight of the downcast air. This air column acts to force the air through the airways

of the mine. An air column always exists where the intake and return currents of air pass through a certain vertical height, and have different temperatures. This is the case whether the opening is a shaft or a slope; since, in either case, there is a vertical height, which in part determines the height of air column. The other factor determining the height of air column is the difference of temperature between the intake and return. The calculation of the ventilating pressure in natural ventilation is identical with that of furnace ventilation, which is described later.

Ventilation of Rise and Dip Workings.—We have referred to the air column existing either in vertical shafts or slopes as the motive column or ventilating motor. Such an air column will be readily seen to exist in any rise or dip workings within the mine, and may assist or retard the circulation of the air-current through the mine. It is this air column that renders the ventilation of dip workings easy, and that of rise workings correspondingly difficult, depending, however, on the relative temperature of the intake and return currents; the latter usually is the warmer of the two, which gives rise to the air column. The influence of such air columns must always be taken into account in the calculation of any ventilation. This is often neglected

The influence of air columns in rise or dip workings, within the mine, becomes very manifest where, from any reason, the main intake current is increased or decreased. For example, a mine is ventilated in two splits, a *rise* and a *dip* split; a current of 50,000 cu. ft. of air is passing in the main airway, 30,000 cu. ft. passing into the dip workings, and 20,000 into the rise workings. A fall of roof in the main intake airway, or other cause, reduces the main current from 50,000 to 35,000 cu. ft. Instead, now, of 21,000 cu. ft. going to the dip workings and 14,000 to the rise workings, we find that this proportion no longer exists, but that the dip workings are taking *more* than their proportion of air, and the rise workings *less*. Thus, the circulation being decreased to 35,000 cu. ft., the dip workings will probably take 25,000 cu. ft., and the rise workings 10,000 cu. ft. On the other hand, had the intake current been *increased* instead of *decreased*, the *rise* workings would then take more than their proportion, while the *dip* workings would take less. The reason for this distribution is evident; suppose, for example, the intake or mine pressure is 3 in. of water gauge, and in the dip workings there is $\frac{1}{2}$ in. of water gauge acting to assist ventilation, while a like water gauge of $\frac{1}{2}$ in. in the rise workings acts to retard ventilation. The effective water gauge in the dip workings is therefore $3\frac{1}{2}$ in., while the effective water gauge in the rise workings is $2\frac{1}{2}$ in., or they are to each other as 7 : 5. If, now, the mine pressure is decreased to, say, 2 in., the effective rise and dip pressures will be, respectively, $2\frac{1}{2}$ in. and $1\frac{1}{2}$ in., or as 5 : 3. We observe, before the decrease, the dip pressure was $\frac{7}{5}$, or 1.4, times the rise pressure, while after the decrease took place in the mine pressure, the dip pressure became $\frac{5}{3}$, or 1.66, times the rise pressure. The relative quantities passing in the dip split before and after the decrease took place, as compared with the quantities passing in the rise split, will be as the $\sqrt{1.4} : \sqrt{1.66}$, showing an increase of proportion. Now, instead of a *decrease* taking place in the mine pressure, let us suppose it is *increased*, say, from 3 in. to 4 in. The effective pressures in the dip and rise workings will then be, respectively, $4\frac{1}{2}$ in. and $3\frac{1}{2}$ in., or they will be to each other as 9 : 7, instead of 7 : 5. Here we observe that the dip pressure is $1\frac{2}{7}$, or 1.15, times the rise pressure, instead of 1.4. The relative quantities, therefore, passing in the *dip* split, before and after the increase of the mine pressure, as compared with the quantities passing in the rise split, will be in the ratio of $\sqrt{1.4} : \sqrt{1.15}$, showing a decrease of proportion. We observe that any alteration of the mine pressure by which it is increased or decreased does not affect the inside dip or rise columns, and hence the disproportion obtains. In case of a decrease of the mine pressure, the dip workings receive more than their proportion of air, and in case of an increase of the mine pressure, they receive *less* than their proportion of air.

Influence of Seasons.—In any ventilation, air columns are always established in slopes and shafts, owing to the relative temperatures of the outside and inside air. The temperature of the upcast, or return column, may always be assumed to be the same as that of the inside air. The temperature of the downcast, or intake column, generally approximates the temperature of the outside air, although, in deep shafts or long slopes, this temperature may be changed considerably before the bottom of the shaft or slope is reached, and

consequently the average temperature of the downcast, or intake, is often different from that of the outside air. The difference of temperatures will also vary with the season of the year. In winter the outside temperature is below that of the mine, and the circulation in shafts and slopes is assisted, since the return columns are warmer and lighter than the intake columns for the same circulation. In the summer season, however, the reverse of this is the case. The course of the air-current will thus often be changed. When the outside temperature approaches the average temperature of the mine, there will be no ventilation at all in such mines, except such as is caused by accidental wind pressure.

In **furnace ventilation** the temperature of the upcast column is increased above that of the downcast column by means of a furnace. The chief points to be considered in furnace ventilation are in regard to the arrangement and size of the furnace. Furnace ventilation should not be applied to gaseous seams, and in some cases is prohibited by law. It is, however, in use in many mines liberating gas. In such cases the furnace fire is fed by a current of air taken directly from the air-course, sufficient to maintain the fire, and the return current from the mine is conducted by means of a dumb drift, or an inclined passageway, into the shaft, at a point from 50 to 100 ft. above the seam. At this point, the heat of the furnace gases is not sufficient for the ignition of the mine gases. The presence of carbonic-acid gas in the furnace gases also renders the mine gases inexplosive. In other cases where the dumb drift is not used, a sufficient amount of fresh air is allowed to pass into the return current to insure its dilution below the explosive point before it reaches the furnace.

Construction of a Mine Furnace.—In the construction of a mine furnace, a sufficient area of passage must be maintained over the fire and around the furnace to allow the passage of the air-current circulating in the mine. The velocity of the current at the furnace should be estimated not to exceed 20 ft. per second, and the entire area of passage calculated from this velocity. Thus, for a current of 50,000 cu. ft. of air per minute, the area of passage through and around the furnace should be not less than

$$\frac{50{,}000}{60 \times 20} = 41\tfrac{2}{3} \text{ sq. ft.}$$

This is a safe method of calculation, notwithstanding the fact that the velocity of the air is often much more than 20 ft. per second, yet the volume of the air is largely increased owing to the increase of temperature.

The length of the furnace bars is limited to the distance in which good firing can be accomplished, and should not exceed 5 ft. The width of the grate will therefore determine the grate area. The grate area must, in every case, be sufficient for the heating of the air of the current to a temperature such as to maintain the average temperature of the furnace shaft high enough to produce the required air column, or ventilating pressure, in the mine. The area A of the grate of the furnace is best determined by the formula $A = \frac{34}{\sqrt{D}} \times \text{H. P.}$, in which A = grate area in square feet; H. P. = horsepower of the circulation; and D = depth of shaft in feet. The horsepower for any proposed circulation may always be determined by dividing the quantity of air (cubic feet per minute) by the mine potential X_u, and cubing and dividing the result by 33,000; thus,

$$\text{H. P.} = \left(\frac{q}{X_u}\right)^3 \times \frac{1}{33{,}000}.$$

The furnace should have proper cooling spaces above and at each side; upon one side, at least, should be a passageway or manway. The furnace should be located at a point from 10 to 15 yd. back from the foot of the shaft, at a place in the airway where the roof is strong. This is well secured by railroad iron immediately over the furnace. A good foundation is obtained in the floor, and the walls of the furnace carried up above the level of the grate bars, when the furnace arch is sprung. If possible, a full semicircle should be used in preference to a flat arch. The sides and arch of the furnace should be carried backwards to the shaft; this is necessary in order to prevent ignition of the coal. The walls and arch are constructed of firebrick a sufficient distance from the furnace, and afterwards of a good quality of hard brick; the shaft is also lined with brick or protected by sheet iron a sufficient height to prevent the ignition of the curbing.

Air Columns in Furnace Ventilation.—As previously stated, natural ventilation and furnace ventilation are identical, in so far as in each the ventilating motor is an air column. This air column is an imaginary column of air whose weight is equal to the difference between the weights of the upcast and downcast columns. The upcast and downcast columns in furnace ventilation are sometimes referred to as the primary and secondary columns, respectively. The *primary* or *furnace column* is, in nearly every case, a vertical column, and consists of a single air column whose average temperature is easily approximated. According to the manner of opening the mine, whether by shaft, slope, or drift, the *secondary* column may be a *vertical column* in the shaft, an *inclined column* in the slope, or an *outside air column* in case of a *drift* opening. Again, it is to be observed that in case of a slope opening where the top of the furnace shaft is much higher than the mouth of the slope, and the dip of the slope is considerable, the *secondary column* consists of *two* columns of different temperatures, an *outside air column* and the *slope column*. These two parts of the secondary column must be calculated separately, and their sum taken for the weight of the secondary column. The level of the top of the furnace shaft determines the top of both the primary and secondary columns, whether these columns are in the outer air or in the mine. The weight of the upcast or primary column is largely affected by its gaseous condition. For example, if the return current from the mine is laden with blackdamp CO_2, its weight will be much increased, since this gas is practically $1\frac{1}{2}$ times as heavy as air, while, if laden with marsh gas, or firedamp mixture, its weight will be considerably reduced. These causes decrease and increase, respectively, the ventilating pressure in the mine.

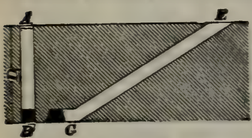


FIG. 7.

Inclined Air Columns.—In a slope opening, the air column is inclined; it is none the less, however, an air column, and must be calculated in the same manner as a vertical column whose vertical height corresponds to the amount of dip of the slope. Fig. 7 shows a vertical shaft and a slope, the air column in each of these being the same for the same temperature. The air column in all dips and rises must be estimated in like manner, by ascertaining the vertical height of the dip.

Calculation of Ventilating Pressure in Furnace Ventilation.—The ventilating pressure in the mine airways, in natural or in furnace ventilation, is caused by the difference of the weights of the primary and secondary columns. Air always moves from a point of higher pressure toward a point of lower pressure, and this movement of the air is caused by the difference between these two pressures. In this calculation each column is supposed to have an area of base of 1 sq. ft. Hence, if we multiply the weight of 1 cu. ft. of air at a given barometric pressure, and having a temperature equal to the average temperature of the column, by the vertical height D of the column, we obtain not only the weight of the column but the pressure at its base due to its weight. Now, since the ventilating pressure per square foot in the airway is equal to the difference of the weights of the primary and secondary columns, we write

$$p = \left(\frac{1.3253 \times B}{459 + t} - \frac{1.3253 \times B}{459 + T}\right) \times D.$$

EXAMPLE.—Find the ventilating pressure in a mine ventilated by a furnace, the temperatures of the upcast and downcast columns being, respectively, 350° F. and 40° F., the depth of the upcast and downcast shafts being each 600 ft., and the barometer 30 in.

Substituting the given values in the above equation, we have

$$p = 1.3253 \times 30 \times 600 \left(\frac{1}{459 + 40} - \frac{1}{459 + 350}\right) = 18.32 \text{ lb. per sq. ft.}$$

Calculation of Motive Column or Air Column.—It is often convenient to express the ventilating pressure p (lb. per sq. ft.) in terms of air column or motive column M, in feet. The height of the air column M is equal to the pressure p divided by the weight w of 1 cu. ft. of air, or $M = \frac{p}{w}$. The expression for motive column may be written either in terms of the upcast air or of the downcast air, the former giving a higher motive column than the latter for the same pressure, since the upcast air is lighter than that of the

downcast. As the surplus weight of the downcast column of air produces the ventilating pressure, it is preferable to write the air column in terms of the downcast air, or, in other words, to consider the air column as being located in the downcast shaft, and pressing the air downwards and through the airways of the mine. If we divide the expression previously given for the ventilating pressure by the weight of 1 cu. ft. of downcast air $\left(\frac{1.3253 \times B}{459 + t}\right)$, we obtain for the motive column, after simplifying, $M = \left(\frac{T-t}{459 + T}\right) \times D$, which is the expression for motive column in terms of the downcast air.

If, on the other hand, we divide the expression for the ventilating pressure by the weight of 1 cu. ft. of upcast air $\left(\frac{1.3253 \times B}{459 + T}\right)$, we obtain $M = \left(\frac{T-t}{459 + t}\right) \times D$, which is the expression for motive column in terms of the upcast air.

Influence of Furnace Stack.—To increase the height of the primary or furnace column, a stack is often erected over the mouth of the furnace shaft. The effect of this is to increase the ventilating pressure in the mine in proportion to the increased height of the primary column, and to increase the quantity of air passing in the mine in proportion to the square root of this height. Thus, the square root of the ratio of the heights of the primary column, before and after the stack is erected, is equal to the ratio of the quantities of air passing before and after the erection of the stack. Or, calling these quantities q_1 and q_2, and the height of stack d, we have

$$\sqrt{\frac{D+d}{D}} = \frac{q_2}{q_1}, \text{ or } q_2 = \sqrt{\frac{D+d}{D}} \times q_1.$$

MECHANICAL VENTILATORS.

A large number of **mechanical ventilators** have been invented and applied, with more or less success, to the ventilation of mines. The earliest type of ventilator was the *wind cowl*, by which the pressure of the wind at the surface was brought to bear effectively upon the mine airways by the action of a cowl whose mouth could be turned toward the wind; this was naturally very unreliable. The *waterfall* was also extensively applied at one time, but its application could only be made where there was a reliable source of water supply, and where the drainage of the mine could be effected through a tunnel, or where the mine opening could be placed in connection with such a waterfall outside of the mine. Where these conditions are obtained, as is the case in some mountainous districts, the waterfall is still in use, as it is an effective means of ventilation, and is economical. Its application, however, must be limited to the ventilation of small mines. The *steam jet* is another mechanical device for producing an air-current in the mine. The steam is allowed to issue from a jet at the bottom of an upcast shaft, and, by the force of its discharge, causes an upward current in the shaft. Its use, however, is very limited, and is practically restricted to the ventilation of shafts while sinking. In this connection it may be mentioned, however, that the discharged steam from the mine pumps, where practicable, may be conducted into the upcast shaft; or the discharge pipe from the pumps may be carried up the upcast shaft, its heat increasing the temperature of the shaft, and thereby increasing the motive column and the ventilation.

Fan Ventilation.—Mechanical motors of this type present two distinct modes of action in producing an air-current: (*a*) by propulsion of the air; and (*b*) by establishing a pressure due to the centrifugal force incident to the revolution of the fan. Fans have been constructed to act wholly on one or the other of these principles, while others have been constructed to act on both of these principles combined.

Disk Fans.—The action of this type of fan resembles that of a windmill, except that in the latter the wind drives the mill, while in the former the fan propels the air or produces the wind. This type of fan consists of a number of vanes radiating from a central shaft, and inclined to the plane of revolution. The fan is set up in the passageway between the outer air and the mine airways. Power being applied to the shaft, the revolution of the

vanes propels the air, and produces a current in the airways. The fan may force the air through, or exhaust the air from, the airways, according to the direction of its revolution. This type of fan is most efficient under light pressures. It has found an extensive application in mining practice, and has a large number of devotees, but has been replaced to a large degree in the ventilation of extensive mines. This type of fan acts wholly by propulsion.

Centrifugal fans include all fans that act solely on the centrifugal principle, and those that combine the centrifugal and propulsion principles. The action of the fan, whether by centrifugal force alone, or combined with propulsion, depends on the form of the fan blades. In this type of fan, the blades are all set at right angles to the plane of revolution, and not inclined, as in the disk fan just described. The blades may, however, be either radial blades, sometimes spoken of as paddle blades, or they may be inclined to the radius either forward in the direction of revolution, or backward. When the blades are radial, the action of the fan is centrifugal only. The inclination of the blades backward from the direction of motion gives rise to an action of propulsion, in addition to the centrifugal action of the fan. The blades in this position may be either straight blades in an inclined position, as in the original Guibal fan, or they may be *curved* backward in the form of a spiral, as in the Schiele and Waddle fans.

Centrifugal fans may be (*a*) exhaust fans or (*b*) force fans or blowers. In each, the action of the fan is essentially the same; i. e., to create a difference of pressure between its intake or central opening, and its discharge at the circumference. The centrifugal force developed by the revolution of the air between the blades of the fan causes the air within the fan to crowd toward the circumference; as a result, a depression is caused at the center and a compression at the circumference, giving rise to a difference of pressure between the intake and the discharge of the fan.

Exhaust Fans.—If the intake opening of the fan be placed in connection with the mine airways, and the discharge be open to the atmosphere, the fan will act to create a *depression* in the fan drift leading to the mine, which will cause a flow of air through the mine airways and into and through the fan. In this case, the fan is exhausting, its position being ahead of the current that it produces in the airway. The atmospheric pressure at the intake of the mine forces the air or propels the current toward the depression in the fan drift caused by the fan's action.

Force Fans and Blowers.—If the discharge opening of the fan be placed in connection with the mine airways, a compression will result in the fan drift owing to the fan's action, and the air will flow from this point of compression through the airways of the mine, and be discharged into the upcast, and thence into the atmosphere. The ventilating pressure in the case of either the exhaust fan or the force fan is equal to the difference of pressure created by the fan's action. In the former case, when the fan is exhausting, the absolute pressure in the fan drift is equal to the atmospheric pressure less the ventilating pressure, while in the latter case, when a fan is forcing, the absolute pressure in the fan drift is equal to the atmospheric pressure increased by the ventilating pressure. This gives rise to two distinct systems of ventilation, known as (*a*) *vacuum system* and (*b*) *plenum system*.

Vacuum System of Ventilation.—In this system, the ventilation of the mine is accomplished by creating a depression in the return airway of the mine. This depression may be created by the action of an exhaust fan, as just described, or by the action of a furnace. In either case, the absolute pressure in the mine is below that of the atmosphere, or, we may say, the mine is ventilated under a pressure *below* the atmospheric pressure. This system has many points of advantage over the plenum system, and for years was considered by many the only practicable system of ventilation. Its application, however, is controlled by conditions in the mine with respect to the gases liberated, the arrangement of the haulage system, etc.

Plenum System of Ventilation.—In this system, the air-current is propelled through the mine airways by means of the compression or ventilating pressure created at the intake opening of the mine. This ventilating pressure may be established by a fan, waterfall, wind cowl, or any other mechanical means at hand. In this system, the absolute pressure in the mine is above that of the atmosphere; or, as we say, the mine is ventilated under a pressure *above* the atmospheric pressure.

Comparison of Vacuum and Plenum Systems.—No hard-and-fast rule can be made to apply in every case, as each system has its particular advantages.

In case of a sudden stoppage of the ventilating motor at a mine, there is, in the vacuum system, a rise of mine pressure, instead of a fall, and the gases are driven back into the workings for a while, while, in the plenum system, any stoppage of the ventilating motor is followed at once by a fall of pressure in the mine, and mine gases expand more freely into the passageways at the very moment when their presence is most dangerous. This point must be carefully considered in the ventilation of deep workings. In shallow workings, the plenum system is often advantageous, especially if there is a large area of abandoned workings that have a vent or opening to the atmosphere, either through an old shaft or through crevices extending to the surface. Every crevice or other vent becomes a discharge opening by which the mine gases find their way to the surface, and the gases accumulating in the old workings are driven back into the workings, and find their way to the surface instead of being drawn into the mine airways, as would be the case in an exhaust system. Any given fall of the barometer affects the expansion of mine gases to a less extent in the plenum system than in the vacuum system, but this small advantage would not give it consideration in determining between the adoption of the one or the other of these two systems; regard must be had, however, to other conditions more vital than this. In the ventilation of gaseous seams, owing to the necessity of making the intake airway the haulage road, the exhaust system has usually been adopted, as the main road is thereby left unobstructed by doors.

TYPES OF CENTRIFUGAL FANS.

We shall only mention the more prominent types of fans that have been or are still in use, giving the characteristic features, as nearly as possible, of each fan. Many fans have been built, however, combining many of the features that originally characterized a single type of fan.

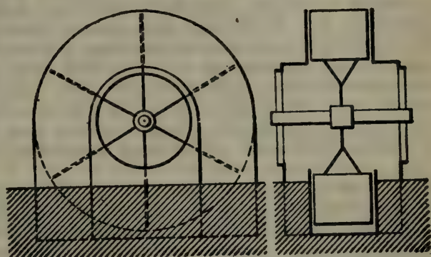


FIG. 8.

Nasmyth Fan.—Fig. 8 is the original type of fan representing straight paddle blades radiating from the center, which is its characteristic feature. This was probably the earliest attempt to apply the centrifugal principle to a mine ventilator, and although not recognized at the time, the fan embodied some of the most essential principles in centrifugal ventilation. It possessed certain disadvantages, however, chief of which was a contracted central or intake opening. The blades, also, were straight throughout their entire length, being normal both to the inner and outer circles of the fan, and thus did not provide for receiving the air without shock at the throat of the fan. The depth of Nasmyth's blades equaled one-half the radius of the fan, which was, under ordinary conditions of mine practice, far too great, and gave the fan a low efficiency.

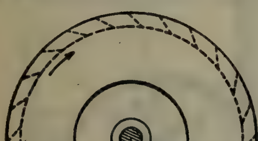


FIG. 9.

Biram's Ventilator. — About 1850, Biram attempted to improve upon the Nasmyth ventilator by reducing the depth of blade so that it was but one-tenth of the radius. The blades were straight, as in Nasmyth's ventilator, but inclined backwards from the direction of motion at a considerable angle. A large number of these blades were employed. This fan was run at a considerable speed, but proved very inefficient. It depended more on the effort of propulsion given to the air than on the centrifugal principle, as the depth of the blade was as much too small as that of Nasmyth's was too great. The intake or central opening in this fan was as contracted as in the former type. See Fig. 9.

Waddle Ventilator.—In this fan, Fig. 10, the inventor attempted to reenforce the discharge pressure at the circumference against the pressure of the

atmosphere. The discharge took place all around the entire circumference of the fan, which was entirely opened to the atmosphere. The blades were curved backward from the direction of motion in spiral form. The width of the blade decreased from the throat toward the circumference, so as to present an inverse ratio to the length of radius. Thus, the area of passage between the fan blades was maintained constant from the throat to the circumference of the fan. The purpose of this was to maintain the velocity of the air through the fan constant, and to fortify the pressure due to the fan against the atmospheric pressure at the point of discharge. The essential features of the Waddle ventilator were, therefore, curved blades tapered toward the circumference, and a free discharge into the atmosphere all around the circumference. This type is the best type of the open-running fan having no peripheral casing, and discharging air into the atmosphere all around the circumference.

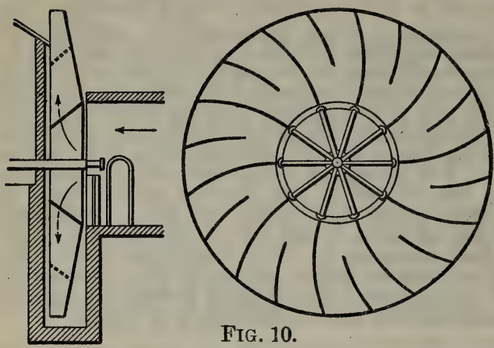


FIG. 10.

Schiele Ventilator.—This ventilator, Fig. 11, was constructed on the same principles as the Waddle ventilator just described, but differed from the latter, as the discharge was made into a spiral chamber surrounding the fan and leading to an expanding or évasé chimney. There was some advantage in this feature, as it protected the fan against the direct influence of the atmosphere, and reduced the velocity of discharge; but, in each of these fans, the intake opening was contracted, and the depth of blade was very great, yielding a comparatively low efficiency.

Guibal Ventilator.—The next important step in the improvement of centrifugal ventilators was introduced by M. Guibal, who constructed a fan, Fig. 12, embodying the features of the Nasmyth ventilator, with the addition of a casing built over the fan to protect its circumference. This casing was, however, a tight-fitting casing, and as such, differed very materially from the Schiele casing. In the Guibal fan the blades were arranged upon a series of parallel bars passing upon each side of the center and at some distance from it. By this construction, the blades were not radial at their inner edge or the throat of the fan. They were curved, however, as they approached the circumference of the fan, so as to be normal or radial at the circumference.

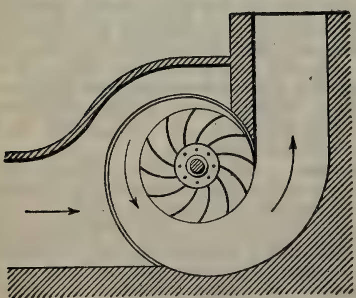


FIG. 11.

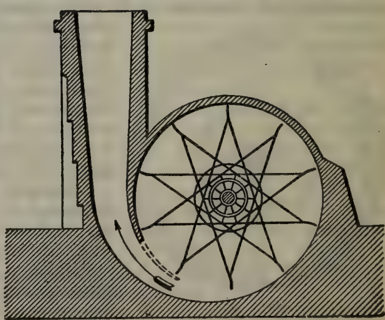


FIG. 12.

The advantage of this construction was to give a strong skeleton or framework to the revolving parts, and, further, each blade was inclined to the radius at its inner extremity, the effect of which was to receive the air upon the blade with less shock than was the case in the Nasmyth ventilator. The intake or central opening, however, was very contracted, and the tight-fitting

casing about the circumference prevented the effective action of the fan during a considerable portion of its revolution. The fan was supplied with an évasé chimney, which was a feature of the Schiele fan, but vibration was so strong that a shutter was required at the cut-off below

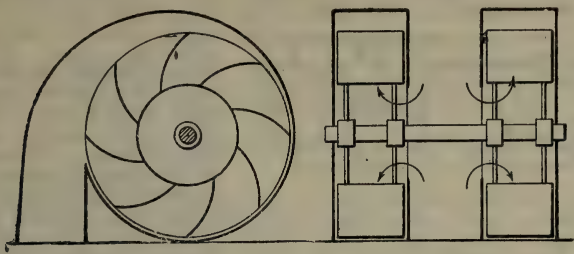


FIG. 13.

the chimney, to prevent it. This shutter was made adjustable, and is known as the *Walker shutter*, having been applied to the fan later.

The Guibal ventilator presents some important and valuable features in the protecting cover, and in the blades meeting the outer circumference radially, and in the air being received with less shock than before. On the whole, it has proved a very efficient ventilator, although much work is lost by reason of its contracted central orifice and tight casing, where the same is used.

Murphy Ventilator.—Fig. 13 consists of twin fans supported on the same shaft and set a few feet apart. Each fan receives its air on one side only, the openings being turned toward each other. This ventilator is built with a small diameter, and is run at a high speed. The blades are curved backwards from the direction of motion. The intake opening is considerably enlarged; a spiral casing generally surrounds the fan, and in every respect this fan makes an efficient high-speed motor. It has received considerable favor in the United States, where it has been introduced into a large number of mines.

Capell Ventilator.—Perhaps none of the centrifugal ventilators have been as little understood in regard to their principle of action as the Capell fan. The fan is constructed along the lines of the Schiele ventilator, but differs from that ventilator in the manner of receiving its intake air and delivering the same into the main body of the fan. Here, and revolving with it, is a set of smaller supernumerary blades. These blades occupy a cylindrical space within the main body of the fan, and are inclined to the plane of revolution so as to assist in deflecting the entering air through small ports or openings into the main body of the fan, where it is revolved and discharged at the circumference into a spiral space resembling that surrounding the Schiele fan. The larger blades of this fan are curved backwards as the Schiele blades, but are not tapered toward the circumference. The fan is capable of giving a high water gauge, and is efficient as a mine ventilator. The space surrounding the fan is extended to form an expanding chimney. The fan may be used either as an exhaust fan or a blower. The best results in the United States have been obtained by blowers. In Germany, where this fan is in general use, there are no blowers.

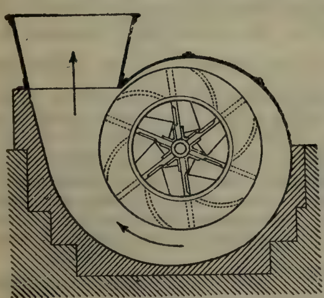


FIG. 14.

The **position of the fan,** whether used as an exhaust or blower, should be sufficiently removed from the fan shaft to avoid damage to the fan in case of explosion in the mine. Even in non-gaseous mines, the fan should be located a short distance back from the shaft mouth, to avoid damage due to settlement. Connection should be made with the fan shaft by means of an ample drift, which should be deflected into the shaft so as to produce as little shock to the current as possible. In

case of gaseous seams, explosion doors should be provided at the shaft mouth. The ventilator at every large mine should be arranged so that it may be converted from an exhaust to a blow-down fan at short notice. This is managed by housing the central orifices or intake of the fan in such a manner as to connect them directly with the fan drift. A large door $a\,b$, Fig. 15, is arranged at the foot of the expanding chimney, the latter being placed between the fan and the shaft. This door, when the fan is exhausting, is in the lower position $a\,b$, and then forms a portion of the spiral casing leading to the chimney. When the fan is blowing, however, the door is swung upwards so as to occupy the position $a\,c$, being tangent to the cut-off at c, thereby closing the discharge into the chimney and causing it to enter the fan drift behind the door. At the same time, the positions of the two doors, $e\,d$ and $f\,d$, in the fan drift, are changed to $e\,t$ and $f\,s$, respectively, to open the fan drift to the discharge from the fan, and to close the openings leading from the fan drift to the housing upon each side of the fan, while another set of doors $A\,A$ upon each side of the fan, in the housing, which were previously closed tightly, are now set wide open to admit the outside air to the intake openings of the fan. The fan is thus made to draw its air from the atmosphere, and discharge it into the fan drift, instead of drawing its air from the fan drift and discharging into the chimney, as before.

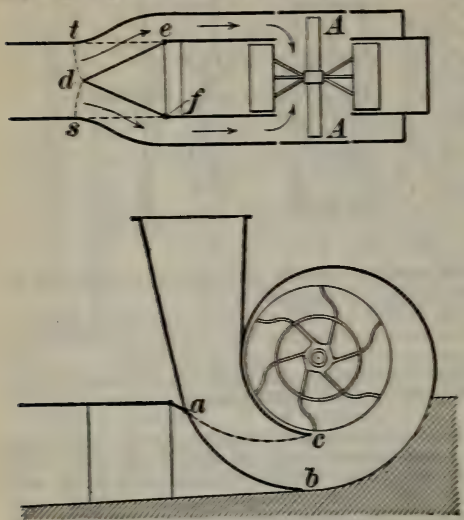


FIG. 15.

The **manometrical efficiency** of a fan is the ratio between its effective and theoretical *pressures*. It has been assumed that the theoretical pressure due to the fan's action is given by the equation $h = \frac{u^2}{g}$, or $i = \frac{u^2 \times 1.2 \times 12}{g \times 1{,}000}$, u being, as before, the tangential speed (feet per second), and g the force of gravity (32.16); h = head of air column in feet; i = water gauge in inches.

The term **mechanical efficiency**, as applied to the ventilator, is the ratio between its effective and theoretical *powers*. In estimating the efficiency of a ventilator, it is customary, though incorrect, to estimate the theoretical power of the fan from an engine card taken from the steam cylinder of the fan engine. The efficiency of the steam engine is thus confused with the efficiency of the ventilator. Mr. Beard gives the following formula for the theoretical work of the fan per minute: $U = .001699 \frac{m^3 - 1}{m^3} \sqrt{V}\, R^3\, b\, n^2$, in which m = ratio between outer and inner diameters of fan ($D = m\,d$), and V = velocity (feet per minute) of air in fan drift; R = outer radius of fan blades (feet); b = breadth of fan blades (feet); n = number of revolutions of fan per minute. If we divide the power upon the air, as determined by the expression $q\,p$, by the theoretical work given in the last equation, we obtain the value of the coefficient of efficiency. According to this formula the efficiency of the ventilator changes with the speed, decreasing as the speed increases, but not in the same ratio. An expression for the coefficient of efficiency of a ventilator is given by Beard as follows: $K = \frac{163{,}600^2}{c\,X^3 + 163{,}600^2}$.

The factor c is a constant of design whose value may vary from 2 to 7, but for an ordinary design, the value $c = 4$ may be taken. This factor has reference to the equipment of the machine with respect to its efficiency for passing an air-current through itself with least resistance. Thus, where the ventilator is to be equipped with intake blades for the deflection of the air-current into the motor, and with straight radial blades having only a forward

curve at the lip of the blade to avoid the shock of the entry air against the revolving blades, and the spiral casing starting a short distance upon the cut-off and extending uniformly around the circumference of the fan, the value of this constant may be 2 or 3. Where none of these accessories to the efficiency of the fan is employed, the value of c may be as high as 7.

FAN CONSTRUCTION.

Size of Central Orifice.—The velocity of the intake should vary between 1,000 ft. and 1,500 ft. per minute, while 1,200 ft. may be used for fan calculations. If d = diameter of opening, and q = quantity of air passing per minute, $d = \sqrt{\frac{q}{1,200 \times .7854}}$ for single-intake fans, and $d = \sqrt{\frac{q}{2,400 \times .7854}}$ for double-intake fans.

Upon entering the fan the air travels in a radial direction; this change of direction is accompanied by a slight reduction of the velocity, hence the throat area of the fan must be slightly in excess of the intake area. The *throat* is the surface of the imaginary cylinder that has for its two bases the two intake openings of the fan, and for its length the width of the fan, = $\pi d b$. [The throat area is commonly made 1.25 times the total area of the intake orifices, which gives for breadth of blade $b = \frac{5}{8} d$ for double intake, and $b = \frac{5}{16} d$ for single intake.—*Beard.*]

Diameter of Fan.—Murgue assumes the tangential velocity of the blade tips (u) to create a depression double that due to the velocity as expressed by the equation $H = \frac{u^2}{g}$, or if the manometrical efficiency = K, and the effective head produced = h, $h = KH = K\frac{u^2}{g}$, or $u = \sqrt{\frac{gh}{K}}$. From this equation, the tangential velocity (feet per second) may be calculated for any given effective head h. This effective head h is the head of air column effective in producing the circulation in the airway. To convert the effective head of air column into inches of water gauge (i), we have $h = \frac{1,000}{1.2 \times 12} i$. Having found the tangential speed required in feet per second, this is multiplied by 60, to obtain the speed in feet per minute, and dividing this result by the desired number of revolutions per minute, or the desired speed of the ventilator, the outer circumference of the fan blades is obtained. No reference is made in the equation to the quantity of air in circulation, which is determined from the equivalent orifice of the mine and of the fan by the equation $V = \frac{.65\sqrt{2K}\,a\,u}{\sqrt{1 + \frac{a^2}{o^2}}}$, in which V = volume of air (cu. ft. per sec.); a = equivalent orifice of the mine; o = the equivalent orifice of the fan. M. Murgue also uses the equation $h = \frac{Ku^2}{g\left(1 + \frac{a^2}{o^2}\right)}$, and suggests that the value of K for any particular type of machine should be first decided, after which the tangential speed required to produce any given effective head of air column (h) is easily calculated from the formula $u = \sqrt{\frac{gh}{K}}$. The breadth of the blade is left largely to judgment, while this method of calculation gives the same size of fan for any given effective head desired, regardless of the quantity of air to be circulated, which is the same as saying that the ventilator will present the same efficiency when a large amount of air is crowded through its orifice of passage as when a smaller amount of air is necessary.

Mr. Beard uses the following formulas for determining the several dimensions of a ventilating fan:

$$m = \sqrt[3]{\frac{Q}{n^2\sqrt{V}}\left(c + \frac{163,600^2}{X^3}\right) + 1}; \qquad D = \frac{m}{\sqrt{m^3 - 1}}\;\frac{3,770\sqrt{p}}{n\sqrt[4]{K^2 V}};$$

$$b = \frac{385,000,000\,p}{(m^3 - 1)\,n^2 K\sqrt{QV}}; \qquad e = \frac{\sqrt{m^3 - 1}}{170\,m}\sqrt[4]{\frac{X^3 K^2 V}{p}};$$

in which $m = \frac{D}{d}$, which is the ratio between the outer diameter of the fan blades D and the inner diameter of the blade d, which equals the diameter of the intake orifice; b = width of fan blade; e = expansion of spiral casing at point of cut-off.

The other symbols stand for the same quantities as previously indicated.

Curvature of Blades.—It was at one time supposed that the curvature of the blades should be such that the radial passage of the air-current would be undisturbed by the revolution of the fan; but fans constructed on this principle gave no adequate results, and the theoretical spiral thus developed was entirely abandoned. A certain curvature of the blade backward, however, is assumed by many to increase the efficiency of the fan. This has not been proved in practice, but the effect of the backward curvature appears simply to necessitate a higher speed of revolution in the fan, in order to obtain the same results as are obtained with radial blades.

The Guibal blade, radial at its outer extremity, or normal to the outer circumference, and curved forward in the direction of motion, at its inner extremity, so that the lip of the blade approaches tangency to the throat circle, seems the most effective blade in centrifugal ventilation.

Tapered Blades.—The object of the taper is to produce a constant area of passage from the throat to the circumference of the fan, and thus prevent the reduction of the velocity of the current in its passage through the fan. This feature presents an attempt similar to that attempted by the curvature of the blades, to hasten the passage of the air through the fan. It has not been proved, however, to have produced any beneficial result, except in the strengthening of the discharge pressure against the atmospheric pressure, in *open-running fans*. On the other hand, the slowing up of the air in its passage through a covered fan has by no means been proved a detriment, but is assumed by many to be an advantage, inasmuch as the air thus remains longer within the influence of the fan blades.

The **number of blades** depends on the size of the fan. An increased number strengthens the fan's action at the circumference, or supports the air at that point, and thus prevents the backlash or the reentry of air into the fan, due to the eddies occurring at the circumference when the blades are too far apart. To a certain extent, the number of blades is modified by the speed of revolution, high-speed motors requiring a somewhat lesser number, while low-speed motors require more. In any case, the number of blades should not be so great as to abnormally increase the resistance to the air-current. In general, the distance upon the outer circumference from tip to tip of the fan blades should be from 2 to 3 times the depth of the blade.

The **spiral casing** gradually reduces the velocity of the air and reduces the shock incident to the discharge of the air into the atmosphere. The spiral casing should be so proportioned that the velocity of the flow from the fan blades will be maintained constant around the entire circumference, and this should not be less than the velocity of the blade tips. The expansion e of the casing at the cut-off should be such as to provide a velocity of the air at this point equal to the velocity of the blade tips, according to the equation $e = \frac{Q}{\pi D n b}$, in which D = diameter of fan; n = number revolutions per minute; b = breadth of fan blade.

The **évasé chimney** reduces the velocity of the air, as it is discharged into the atmosphere, to a minimum. The chimney should be sufficiently high to protect the fan from the effect of high winds, but should not extend too far above the fan casing, the point of cut-off being situated below this, at about the level of a tangent to the throat circle at its lower side.

High-Speed and Low-Speed Motors.—The question of speed of the ventilating motor is largely an open one, inasmuch as the same work may be performed by a small ventilator running at a high speed as is performed by a large ventilator running at a low speed.

It is important to design a mine ventilator at a speed such as to admit of its being increased in case of emergency. If the ventilator has been designed at a high speed, a demand for an increase of speed cannot be met as readily as when the ventilator is designed at a medium or low speed; in other words, the exigencies of mine ventilation demand that a ventilator shall be capable of greatly increased speed.

Fan Tests.—A large number of fan tests have been made, from time to

time, on different types of fans and under different conditions, with respect to the resistance against which the fan is operated, and the quantity of air required, and the speed of the ventilator. The experiments have resulted, to a large extent, in tabulating a mass of contradictory data. The conditions that affect the yield of the centrifugal ventilator are so numerous, and the tabulation of the necessary data has been so often neglected in these experiments, as to render them practically useless for the purpose of scientific investigation. In conducting a reliable fan test, the following points should be observed: (1) Take the velocity, pressure, and temperature of the air at the same point in the airway, as nearly as practicable. This point should be selected near the foot of the downcast shaft, or in the fan drift at a suitable distance from the fan, to avoid oscillations of pressure and velocity. (2) The area of the fan drift should be uniform for a suitable distance in each direction from the point of observation, and this area should be carefully measured. (3) Take the anemometer readings at different positions in the airway, so as to obtain an average reading over the entire sectional area. Do not interpose the body in this area so as to decrease the sectional area of the airway. (4) Take outside temperature of the air and the barometric pressure at the time of making the test. (5) The intake and discharge openings of the fan should be protected against wind pressure. (6) At least three observations should be made, at as many different speeds of the ventilator, and the number of revolutions of the fan carefully observed and recorded for each observation.

Mr. R. Van A. Norris (Trans. A. I. M. E., Vol. XX, page 637) gives the results of a large number of experiments performed upon different mine ventilating fans. This table, like all other tabulated fan tests, shows a large amount of contradictory data. The conclusions drawn by Mr. Norris from these tests are interesting and would be given here excepting that they might be misleading if considered apart from the description of the experiments and the discussion leading up to the conclusions.

CONDUCTING AIR-CURRENTS.

Doors.—A mine door is used for the purpose of deflecting the air-current from its course in one entry so as to cause it to traverse another entry, at the same time permitting the passage of mine cars through the first entry. The essential points in the construction of a mine door are that it shall be hung from a strong door frame in such a manner as to close *with* the current. The door should be hung so as to have a slight fall. If necessary, canvas flaps may be supplied to prevent leakage around the door, and particularly at the bottom. *Double* doors are used on main entries at the shaft bottom, or at any point where the opening of the door causes a stoppage of the entire circulation of the mine. Such doors should be placed a sufficient distance apart to allow an entire trip of mine cars to stand between them, so that one of the doors will always be closed while the other is open.

Stoppings.—Stoppings are used to close break-throughs that have been made through two entries, or rooms, for the purpose of maintaining the circulation as the workings advance; also to close or seal off abandoned rooms or working places. Stoppings must be air-tight and substantially built. A good form of stopping is constructed by laying up a double wall of slate, having about 8 or 10 in. of space between the two walls. This space is filled, as the building progresses, with dirt taken from the roadways, or other fine material. In the building of stoppings to seal off mine fires, it is important to begin the work at the end nearest the return air, and work toward the intake end, which should be sealed off last. This method avoids the danger of an explosion occurring within the workings that are being sealed off, as the necessary dilution of the gases within is accomplished by the fresh air-current, until the intake is finally sealed. Where the intake is sealed first, an explosion is almost inevitable, as has been proved in many instances.

Air Bridges.—An air bridge is a bridge constructed for the passage of air across and over another airway, this being called an *overcast;* or, the crossing may be made to pass under the airway, this being called an *undercast.* In almost every instance, overcasts are preferable to undercasts for several reasons. An undercast is liable to be filled with water accumulating from mine drainage; it is also liable to fill with heavy damps from the mine, when the ventilation is sluggish, and to offer considerable resistance to the free passage of the air-current. An undercast can never be maintained as air-tight as an overcast, on account of the continual travel through the

haulageway or passageway leading over it. This continual passing over the bridge causes a fine dust to sift into the airway and mingle with the air-current. All these objections are overcome in the construction of the overcast.

An **air brattice** is any partition erected in an airway for the purpose of deflecting the current. A thin board stopping is sometimes spoken of as a brattice; but the term applies more particularly to a thin board or canvas partition running the length of an entry or room and dividing it into two airways, so that the air will be obliged to pass up one side of the partition and return on the other side of the partition, thus sweeping the face of the heading or chamber. Such a temporary brattice is often constructed by nailing brattice cloth or heavy duck canvas to upright posts set from 4 to 6 ft. apart along one side of the entry a short distance from the rib.

Curtains.—These are sometimes called canvas doors. Heavy duck, or canvas, is hung from the roof of the entry to divide the air or deflect a portion of it into another chamber or entry. Curtains are thus used very often previous to setting a permanent door frame. They are of much use in longwall work, or where there is a continued settlement of the roof, which would prevent the construction of a permanent door; also, in temporary openings where a door is not required.

HOISTING AND HAULAGE.

HOISTING.

There are two general systems of hoisting in use: (*a*) *Hoisting without attempting to balance the load.* In this system, the cage and its load are hoisted by an engine and lowered by gravity. (*b*) *Hoisting in balance.* In this system, the descending cage or a special counterbalance assists the engine to hoist the loaded ascending cage. Hoisting in balance is usually effected by the use of (1) double cylindrical drums; (2) flat ropes winding on reels; (3) conical drums; (4) the Koepe system; (5) the Whiting system.

1. **Double cylindrical drums** are widely used: they consist essentially of an engine coupled directly or else geared to the common axis of the drums. The drums are usually provided with friction or positive clutches, and brakes, so that they can be run singly if desired, or the load can be lowered by gravity and the brake.

2. **Flat ropes** wound on reels are sometimes used either for unbalanced hoisting with a single reel or for balanced hoisting with a double reel. With the double reels, the load on the engine is balanced throughout the entire hoist, for, as the rope is wound on the reel, the diameter of the reel is increased, and the lever arm through which the power of the engine is applied is also increased and the mechanical efficiency of the hoisting system decreased. Thus, when the cage is at the bottom of the shaft and the entire weight of the rope is out, giving the maximum load to be hoisted, the drum is of a minimum diameter and the engine has, therefore, its greatest leverage to start the load. A flat rope has the advantage of preventing fleeting, but its first cost, extra weight, wear, and difficulty of repairing have prevented its very general adoption.

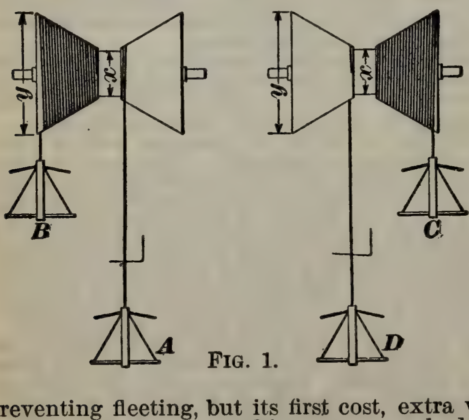


Fig. 1.

3. **Conical Drums.**—A conical drum, Fig. 1, equalizes the load on an engine just as a flat rope on a reel does. On account of the fleeting of the rope, however, the drum must be set at a considerable distance from the shaft to prevent the rope leaving the head-sheave. A tail-rope gives the most

perfect counterbalance, the weight of the cage and rope on each side being exactly equal.

4. In the **Koepe system**, Fig. 2, one rope runs over and the other under driving sheaves *S*. A tail-rope *R* is used, and the head-sheaves *x*, *x′* are placed vertically and at such an angle to each other that their grooves and the groove in the driving sheave are in line. As the main driving shaft is short, the engines can be placed close together, thus requiring a smaller foundation and engine house than for a drum hoist. The objection to the system is the liability of the rope to slipping about the driving sheave, and for this reason a hoisting indicator cannot be depended on. The system is also inconvenient for hoisting from different levels in the same shaft, and, in case of the rope breaking, both cages fall to the bottom.

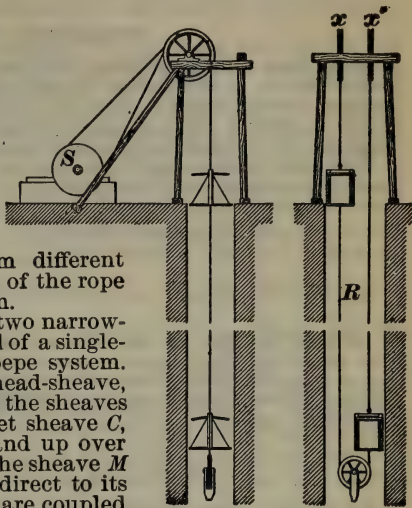


FIG. 2.

5. The **Whiting system**, Fig. 3, uses two narrow-grooved drums placed tandem instead of a single-driving sheave as is used in the Koepe system. The rope passes from the cage *A* over a head-sheave, under the guide sheave *T* and around the sheaves *M*, *F* three times, then out to the fleet sheave *C*, back under another guide sheave, and up over another head-sheave to the cage *B*. The sheave *M* is driven by a motor either coupled direct to its shaft, or geared. The drums *F* and *M* are coupled together by a pair of connecting-rods, like the drivers of a locomotive, and this arrangement makes it possible to utilize all the friction of both drums to drive the rope. Thus a tail-rope is not depended on to produce more friction, though one is generally used as a balance to the loads.

It is best to incline the follower sheave *F* from the vertical an amount

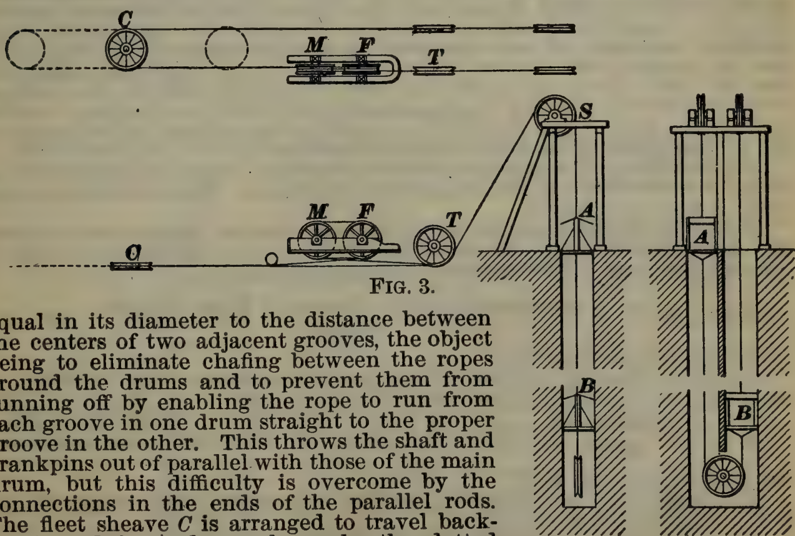


FIG. 3.

equal in its diameter to the distance between the centers of two adjacent grooves, the object being to eliminate chafing between the ropes around the drums and to prevent them from running off by enabling the rope to run from each groove in one drum straight to the proper groove in the other. This throws the shaft and crankpins out of parallel with those of the main drum, but this difficulty is overcome by the connections in the ends of the parallel rods. The fleet sheave *C* is arranged to travel backwards and forwards, as shown by the dotted lines, in order to change the working length of the rope, whereby hoisting can be done from different levels in the shaft.

The **power** used for hoisting is generally steam for the main hoists. Electricity is, however, coming rapidly into use, particularly for smaller hoists

and local installations, and for main hoists in locations where fuel is expensive and water-power available. Gasoline engines are also being used to an increasing degree, particularly for smaller hoists and in local installations, and they are said to give very satisfactory results.

PROBLEMS IN HOISTING.

To Balance a Conical Drum.—Having given the diameter of one end of a conical drum, to determine the diameter of the other end that will equalize the load on the engines. In Fig. 1, call total load at bottom A, empty cage at top B, loaded cage at top C, empty cage plus rope at bottom D, small diameter of drum x, and large diameter y; then, $Ax - By = Cy - Dx$.

EXAMPLE.—In a shaft, the cage weighs 2 tons, the empty car 1 ton, the loaded car 3 tons, and the rope 2 tons. What should be the small diameter of a conical drum whose large diameter is 30 ft.?

$$(2 + 2 + 3)x - (2 + 1)30 = (2 + 3)30 - (2 + 2 + 1)x,$$

or

$$7x - 90 = 150 - 5x.$$

$$\therefore \quad 12x = 240,$$

$$x = 20 \text{ ft.}$$

To Find the Size of the Hoisting Engine.—Let D = diameter of cylinder, P = mean effective steam pressure in cylinders, r = ratio of stroke to diameter of cylinder, and w = work per revolution required to be done; then, by making one cylinder capable of doing the work, n = number of strokes, u = work per minute (ft.-lb.).

$$D = 1.97\sqrt[3]{\frac{w}{Pr}}, \text{ or } D = \sqrt[3]{\frac{u}{.7854\,Prn}}.$$

EXAMPLE.—What should be the size of the cylinders of a hoisting engine that is to perform 152,580 ft.-lb. of work per revolution, if the mean effective pressure is 45 lb. per sq. in. and the stroke of the piston is twice its diameter?

$$D = 1.97\sqrt[3]{\frac{152{,}580}{45 \times 2}} = 23.5 \text{ in.}$$

To get up speed in a few seconds, more power than would be represented by the load to be lifted is required. Mr. Percy gives the following rule for this case: In a properly balanced winding arrangement, with uniform load, multiply the weight of coal in pounds by the average speed of the cage in feet per minute; add one-half to cover the frictional resistances, and call that the *load*. Then the power that must equal this must be the average effective pressure of steam in pounds per square inch on the piston, multiplied by the area of one cylinder in square inches, and multiplied again by the average speed of the piston in feet per minute.

Approximately, the average effective pressure of steam will be two-thirds of the pressure shown on the gauge near the engines. A good average piston speed is 400 ft. per minute.

To Find the Actual Horsepower of an Engine for Hoisting Any Load Out of a Shaft at a Given Rate of Speed.—To the weight of the loaded car add the weight of the rope and cage. This will give the gross weight.

Then, $\text{H. P.} = \dfrac{\text{gross weight in lb.} \times \text{speed in ft. per minute}}{33{,}000}$; add $\frac{1}{3}$ for contingencies, friction, etc.

EXAMPLE.—Having a shaft 600 ft. deep, gross weight of load 20,000 lb., to be hoisted in $1\frac{1}{2}$ minutes, what horsepower is required?

$\text{H. P.} = \dfrac{20{,}000 \times 400}{33{,}000} = 243$ H. P., nearly. To which add $\frac{1}{3}$ for contingencies, and we have 324 H. P.

In a shaft with two hoistways, use the net weight + the weight of one rope, instead of the gross weight.

The following rules regarding winding engines are given by Percy:

1. **To Find the Load That a Given Pair of Direct-Acting Engines Will Start.** Multiply the area of one cylinder by the average pressure of the steam per square inch in the cylinder, and twice the length of the stroke. Divide this by the circumference of the drum, and deduct $\frac{1}{3}$ for friction, etc.

EXAMPLE.—Given a pair of engines, cylinders 20 in. diameter by 40 in. stroke, the drum 12 ft. diameter, and the pressure at steam gauge 50 lb., steam cut-off at $\frac{2}{3}$, average pressure of steam in cylinder 48.2 lb.

Then, area of cylinder = 314.16 sq. in. $314.16 \times 48.2 \times 80 = 1,211,400.96$.

The circumference of the drum = 452.4 in. $1,211,400.96 \div 452.4 = 2,677$.

$\frac{2}{3}$ of 2,677 = 1,784 lb., or the net load.

The gross load would include the weight of rope, cage, and car, but as these are balanced by the descending rope, cage, and car, the net load only is found. The drum mentioned is cylindrical.

2. **Knowing the Load and the Diameter of a Cylindrical Drum, and the Length of Stroke, the Cut-off and Pressure of Steam at Steam Gauge, to Find the Area and Diameter of Cylinders of a Pair of Direct-Acting Engines.**—Multiply the load by the circumference of the drum, and add one-half for friction, etc. Divide this by the mean average steam pressure, multiplied by twice the length of the stroke.

EXAMPLE.—Having the drum 10 ft. in diameter, the stroke 6 ft., the steam pressure at gauge 60 lb., the cut-off at $\frac{3}{4}$ of stroke, and the load 5 tons, or 11,200 lb.

Then $11,200 \times 31.416$ (circumference of drum) = 351,859. 351,859 + $\frac{1}{2}$ of 351,859 (or 175,930) = 527,789.

The mean average pressure = 56.2 lb. $56.2 \times (6 \times 2) = 674.4$. $527,789 \div 674.4 = 782.6$ sq. in., area of piston.

$782.6 \div .7854 = 996$. $\sqrt{996} = 31.56$ in., or diameter of cylinder.

3. **To Find the Approximate Period of Winding on a Cylindrical Drum With a Pair of Direct-Acting Engines.**—Assume the piston to travel at an average velocity of 400 ft. per minute, and divide this by twice the length of the stroke, and multiply by the circumference of the drum. This gives the speed of cage in feet per minute. Divide the depth of shaft by this, and the result will be the period of winding.

EXAMPLE.—Drum, 31.416 ft. circumference; stroke, 6 ft.; depth of shaft, 1,500 ft.

Then, $400 \div 12 = 33.33$. $33.33 \times 31.416 = 1,047.1$. $1,500 \div 1,047.1 = 1.43$ min., or about 1 min. 26 sec.

4. **To Find the Useful Horsepower During a Winding.**—Multiply the depth of shaft by net weight raised; divide this by number of minutes occupied in winding, and divide again by 33,000.

EXAMPLE.—Net weight, 2 tons = 4,480 lb.; depth, 1,500 ft.; period of winding, 1.43 minutes.

Then, $4,480 \times 1,500 = 6,720,000$. $6,720,000 \div 1.43 = 4,699,301$. $4,699,301 \div 33,000 = 142+$ H. P.

HEAD-FRAMES.

Head-frames are built of wood or steel, and some of the typical forms are shown on pages 275 and 276. They vary in height from 30 to 100 ft., depending on local conditions.

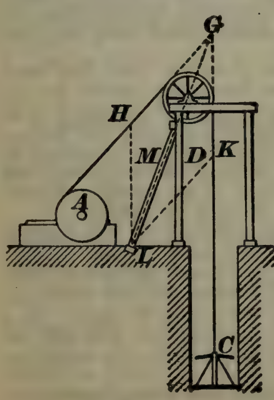


FIG. 4.

The inclined leg of a head-frame should be placed so as to take up the resultant strain due to the load hanging down the shaft and the pull of an engine. Fig. 4 shows the graphical method of determining the direction and magnitude of this resultant force. Produce the direction of the two portions of the rope leading to the drum and down the shaft until they intersect at G, measure off a distance GK to scale to represent the load hanging down the shaft; similarly, measure off GH to the same scale to represent the pull of the engine, complete the parallelogram $GHLK$; the direction of the line GL represents the direction of the resultant force, and its length represents the amount of this force. The inclined leg of the head-frame should be placed as nearly as possible parallel to this resultant line, and should be designed to withstand a compressive strain equal to this resultant.

Head-sheaves are made of iron, being sometimes entirely cast, or else the

rim and hub are cast separately and wrought-iron spokes are used. The former are cheaper and quite satisfactory, but the latter are lighter and stronger, and therefore usually better. The diameter of the sheave depends on the diameter of the rope, and the table giving this will be found on page 120. The groove in the sheave should be wood-lined, to reduce wear on the rope. Wrought-iron spokes should be staggered in the hub and not placed radially.

Guides and conductors are usually of timber rigidly attached to the sides of a shaft. In England and certain parts of Europe, wire ropes are used for guides and are strongly advocated, but they have never found favor in America. These ropes when used are weighted at the bottom, and Percy gives 1 ton for each 600 ft. in depth for each wire as a good weight to be used. When not thus weighted, the ropes are fastened at the bottom and attached to levers at the top, the levers being weighted to produce the requisite tension.

Safety catches usually consist of a pair of toothed cams placed on either side of the cages and enclosing the guides. When the load is on the hoisting rope, these cams are kept away from the guides by suitable springs; but if the rope breaks, the springs come into action and throw the catches or dogs so that they grip the guides, and the tendency to fall increases the grip on the guides.

Detaching hooks are devices that automatically disconnect the rope from the cage in case of overwinding.

HAULAGE.

The magnitude of modern mines and the practice of loading or of treating the coal or ore at a large central station makes the underground haulage of the material one of the most important problems in connection with mining. A good haulage system is now essential to make most mines a commercial success. Haulage may be considered under the following heads:

1. *Inclined Roads.*—Gravity planes, engine planes.
2. *Level Roads.*—Mule haulage, rope haulage (tail-rope and endless rope), motor haulage (steam, electricity, compressed air, or gasoline).

Gravity Planes.—The loaded car or trip hauls the empty car up the grade. Two ropes are attached to a drum so that the rope attached to the loaded car unwinds from the drum as the car descends, while the rope attached to the empty car is wound on the drum and the car thus hauled up the plane. The natural slope of the ground, in a large measure, determines the grade of the incline, but where it is possible to alter the direction of the incline, the grade may be *lessened* by constructing the incline across the slope of the ground. The grade of the incline may be *increased* by carrying the upper landing forwards till a point is reached from which the required grade is obtained.

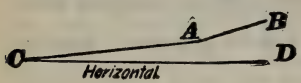


FIG. 5.

The following rule gives suggestions based on practice that has been successful: For lengths not exceeding 500 ft., the minimum grade for the incline should be 5% when the weight of the descending load is 8,000 lb. and that of the ascending load 2,800 lb. Or the inclination should not be less than 5½% if the respective descending and ascending loads are one-half of those just given. When the length of the plane is from 500 to 2,000 ft., the grade should be increased from 5% to 10%, according to the loads. A load of 4,000 lb. on a 10% grade 2,000 ft. long will hoist a weight of 1,400 lb.

The *angle of inertia* is that angle or inclination at which a car will start to move down the slope or plane. The car, when it has once started on this grade, will continue to accelerate its speed as it descends the plane $A\ B$, Fig. 5. If we decrease the angle of inclination until the plane $A\ B$ occupies the position $A\ C$, such that the moving car will continue to move at a uniform velocity instead of accelerating its speed, the angle $D\ C\ A$ will be the *angle of rolling friction*, and the tangent of this angle will be the *coefficient of rolling friction* for the car.

The upper portion of a plane is made steeper than the lower portion so that the trip may start quickly at the head and afterwards maintain a uniform velocity. With a good brake to control the cars, the uniform grade of a central portion of a gravity plane should not fall much below 3°, which corresponds practically to a 5¼% grade.

The *acceleration* f of the haulage system is given by the formula

$$f = \frac{p_1 - p_2}{p_1 + p_2} \times g \times \sin a$$

where p_1 and p_2 are the descending and ascending pulls, respectively.

The *length of steep pitch* is given by the formula

$$l = \frac{v^2}{2f},$$

where v = velocity at which the trip is desired to run.

The maximum tension or pull on the rope which may occur, if it is required to haul the loaded trip up, is

$$T = (W + wl) \sin a + (W + wl) \cos a \times \mu,$$

where W = weight of loaded trip; wl = weight of rope; a = slope angle; μ = coefficient of friction.

EXAMPLE.—Find the possible tension of a rope used to lower a loaded trip of two cars upon a plane 800 ft. long, having a uniform grade of 5% at a speed of 20 miles per hour, using a factor of safety of 10, and letting $\mu = \frac{1}{20}$, the empty cars weighing 1,000 lb. each and carrying a load of 2,000 lb. each.

Assuming w = .88 lb., $T = (6{,}000 + .88 \times 800)(.05 + .04994) = 671$ lb.

To find the number of cars that must run in a trip on a self-acting incline, use the formula

$$N = \frac{(40 \sin a + \cos a) W_3}{(40 \sin a - \cos a) W_1 - (40 \sin a + \cos a) W_2},$$

in which N = number of cars; a = angle of inclination of plane; W_1 = weight in pounds of one loaded car; W_2 = weight in pounds of one empty car; W_3 = weight in pounds of haulage rope; $\frac{1}{40}$ = coefficient of friction.

EXAMPLE.—A gravity plane has an inclination of 8°; it is 2,000 ft. long, the rope weighs 4,000 lb., a loaded car weighs 3,000 lb., and an empty car weighs 1,800 lb. What number of cars must be in the trip to start it?

Substituting values in the above formula, we have

$$N = \frac{(40 \times .13917 + .99027)4{,}000}{(40 \times .13917 - .99027)\,3{,}000 - (40 \times .13917 + .99027)1{,}800} = 13.6.$$

Engine Planes.—With an engine plane, the load is delivered at the foot of the plane and has to be hoisted. The engine may be either at the top or the bottom. The grade of the plane is usually uniform from top to bottom, and there may be a single track, a double track, or three rails with a turnout.

Size of Engines Required for Engine-Plane Haulage.—(*a*) *Engine at Head of Plane, Single Track.*—Calling the load on the engine or the tension of the rope at the winding drum T, the weight of the ascending loaded trip W, the weight of the rope per lineal foot w, and the length of the plane l, the angle of inclination or the slope angle being a, as before, we have

$$T = (W + wl)(\sin a + \mu \cos a).$$

Assume an approximate value for w, and determine T approximately. The size of rope required for this load is then obtained from the table for haulage ropes, and with this new value of w, the correct load on the engine is calculated.

EXAMPLE.—What size of rope will be required to haul up an incline a loaded trip of 10 mine cars weighing 1,000 lb. each, and carrying a load of 2,000 lb. each, the inclination of the plane or the slope angle being 16° and its length 500 yd., assuming for the coefficient of friction $\mu = \frac{1}{40}$?

W = 30,000 lb., and assuming w = .89 lb., $W + wl = 30{,}000 + (.89 \times 1{,}500) = 31{,}335$ lb. $\sin a + \frac{\cos a}{40} = .27564 + \frac{.96126}{40} = .29967$. Hence, $T = 31{,}320 \times .29967 = 9{,}394$ lb. To provide against shock, we double the load or pull on the rope in calculating the size of rope required; thus, $9{,}394 \times 2 = 18{,}788$ lb., and using a factor of safety of 6, we have for the breaking strain of the rope $\frac{18{,}788 \times 6}{2{,}000} = 57$ tons. In the table of wire ropes, a 1⅛" plow-steel rope

presents a breaking strain of 56 tons. Since a $1\frac{1}{8}''$ rope weighs 2 lb. per lineal foot, we have $W + wl = 30{,}000 + (2 \times 1{,}500) = 33{,}000$ lb. Then $T = 33{,}000 \times .29967 = 9{,}889$ lb.

(b) *Engine at Head of Incline, Double Track.*—The load on the engine equals the difference between the gravity pulls of the ascending and descending trips, including the rope, plus the friction pull of both the trips and one rope, since there is only one rope on the plane at any time. Calling the weight of the ascending trip W, as before, and that of the descending trip W_1, we have for the difference of the gravity pulls when the loaded trip is at the foot of the incline, $(W - W_1 + wl) \sin a$, and for the friction pull of the entire moving system $(W + W_1 + wl)\,\mu \cos a$, and $L = (W - W_1 + wl) \sin a + (W + W_1 + wl)\,\mu \cos a$.

Assuming the same conditions as given in the example of the preceding paragraph, we have for the load L on the engine, $L = [10 \times 2{,}000 + 2 \times 1{,}500]\ .27564 + [10 \times (3{,}000 + 1{,}000) + 2 \times 1{,}500] \times \frac{.96126}{40} = 23{,}000 \times .27564 + 43{,}000 \times .02403 = 7{,}373$ lb. instead of 9,394, the unbalanced load for single track.

(c) *Engine at Foot of Incline.*—The load on the engine is the same as in (a), except that the gravity pull is the pull due to the weight of the loaded cars only, the weight of the ascending rope being balanced by the descending rope, while the friction pull is increased by the friction of the descending rope. Calling the load on the engine L, as before, we have, in this case,

$$L = W \sin a + (W + 2wl)\,\mu \cos a.$$

Assuming the conditions of the previous example and calculating the load on the engine for this case, we have $L = 30{,}000 \times .27564 + [30{,}000 + 2(2 \times 1{,}500)]\,.02403 = 9{,}134$ lb.

To Find the Horsepower of an Engine Required to Hoist a Given Load Up a Single-Track Incline in a Given Time.—Multiply the length of the incline in feet by the natural sine of the angle of inclination, which will give you the vertical lift. Divide the vertical lift by the given time in minutes. Multiply this by the gross load, including weight of rope, and divide the product by 33,000.

EXAMPLE.—Length of incline, 600 ft.; angle of inclination, 35°; weight of loaded car and 600 ft. of rope, 5,000 lb.; time of hoisting, 2 minutes. Required, the horsepower.

Sine of $35° = .573576$. $.573576 \times 600 = 344.1456$. $344.1456 \div 2 = 172.728$.

$$\frac{172.728 \times 5{,}000}{33{,}000} = 26+ \text{ H. P.}$$

Add from 25% to 50% for contingencies, friction, etc. In mine practice, 50% is not any too much to add, because the condition of track, cars, etc., is not as good, as a general rule, as on railroad planes.

To Find the Horsepower of an Engine Required to Hoist a Given Load Up a Double-Track Incline in a Given Time.—Proceed as above, using the net load, to which should be added the weight of one rope, instead of the gross load.

ROPE HAULAGE.

The **tail-rope system** of haulage uses two ropes and a pair of drums on the same shaft. The main rope passes from one drum directly to the front of the loaded trip, and the tail-rope passes from the other drum to the large sheave wheel at the end of the road and back to the rear of the loaded trip. While hauling the loaded trip, the drum on which the tail-rope is wound is allowed to turn freely on its journal by throwing its clutch out, while the engine turns the other drum. When the empty trip is being hauled, the clutch on the main-rope drum is thrown out and the one on the tail-rope drum is thrown in. The engine then turns the tail-rope drum and allows the other one to pay out rope as the trip advances.

The tail-rope system is suitable for steep, circuitous, and undulating roads. The trip can be kept stretched at all points, and thus the cars will be prevented from bumping together or from being jerked apart as the trip is passing over changes in the grade. It is undoubtedly the most satisfactory system of rope haulage under the natural conditions of most haulage roads in mines, and especially so where but one road is available for haulage purposes.

CALCULATION OF THE TENSION OF HAULING ROPE.

T = tension or pull upon rope (lb.).
W = weight of loaded trip (lb.).
w = weight of rope per lineal foot (lb.).
l = length of two ropes; equals 2 times the distance from winding drum to tail-sheave (ft.).
d = vertical drop of rope (ft.).
a = slope angle of maximum grade.

$$T = W(\sin a + \mu \cos a) + w(d + \mu l).$$

EXAMPLE.—What size of steel wire rope will be required to haul a trip of 20 mine cars, the weight of the loaded cars being 3,000 lb. each, the depth of the shaft 300 ft., and the distance from the foot of the shaft to the tail-sheave 900 yd., the maximum grade in this haulage being 10°, $\mu = \frac{1}{40}$? Assuming a $\frac{3}{4}''$ rope, weighing .89 lb. per lineal ft.

$$T = 60{,}000\left(.17365 + \frac{.9848}{40}\right) + .89\left(300 + \frac{6{,}000}{40}\right) = \text{say } 12{,}300 \text{ lb., or some-}$$

what over 6 tons.

Referring to the tables for steel haulage ropes with 6 strands of 7 wires each, we find the breaking strain of a $\frac{3}{4}''$ rope, weighing .89 lb. per lineal ft., is 18.6 tons, which will give a factor of safety of about 3. We would, however, use a $\frac{7}{8}''$ or even a 1″ rope, as a change of ropes would then be required less often. Making the necessary corrections for 1″ rope weighing 1.58 lb. per lineal ft., T = 12,607 lb.

The **endless-rope system** uses an endless rope, which is kept running continuously by a pair of drums geared together and set tandem. The drums are comparatively narrow and provided with grooves for the rope to run in. Two drums are necessary to get sufficient friction to drive the rope when the trip is attached to it. The rope is passed around both drums a number of times, depending on the amount of friction desired, without completely encircling either. It then passes to a tension wheel at the rear of the drums and thence to the sheave wheel at the far end of the road and back to the drums. To be used to best advantage, this system requires that the grade be in one direction and that it be necessary to haul cars from a number of places en route. The cars are attached to the rope by friction grips in a manner quite similar to the way in which street cars are attached to cable lines. It is evident, therefore, that any jerking due to the cars bumping together or stretching the hitchings would seriously injure the rope where the grip takes hold. A double road is an essential feature of endless-rope haulage.

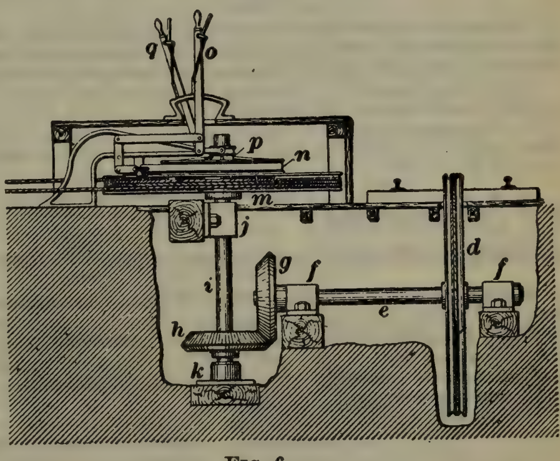


FIG. 6.

The endless-rope system of haulage is best adapted to roads presenting a fairly uniform grade, particularly when the trips are not spaced at fairly regular intervals along the road. Owing to delays in the delivery of the cars by the drivers and to irregularity in unloading at the tipple, it is practically impossible to have the several trips regularly spaced, and in consequence the load on the engine varies greatly. In order to take up any elongation of the rope due either to change in temperature or to stretching, some form of balance car or balance weight is used. This weight should be sufficient to keep the empty rope taut, and any tendency of the rope to slip on the

winding drum may be overcome by increasing the weight in the balance car.

Fig. 6 shows a device for working a district haulage by connecting it with the main haulage. The main rope makes one or two complete turns around a fleet wheel located at the mouth of each district, and then continues on its course. This fleet wheel d is directly connected with the driving sheave m for the district by means of beveled gears g, h, as shown. The driving sheave m is thrown in or out of gear by levers o and q.

To Determine the Friction Pull on an Endless-Rope Haulage.—Let

O = output (lb. per min.); w_1 = weight of mine car (lb.);
v = speed of winding (ft. per min.); w = weight of rope (lb.);
l = length of haulage road (ft.); T = load on the rope (lb.);
c = capacity of mine car (lb.); μ = coefficient of friction.

Then,

$$\frac{l\,O}{v} = \text{weight of material in transit;}$$

$$2\frac{l\,O}{v\,c}w_1 = \text{weight of moving cars, loaded and empty;}$$

$$2\,l\,w = \text{weight of rope;}$$

$$\frac{l\,O}{v}\left(1+\frac{2\,w_1}{c}\right)+2\,wl = \text{entire moving load.}$$

And if the coefficient of friction equals $\frac{1}{40}$,

$$T = \mu\left[\frac{l\,O}{v}\left(1+\frac{2w_1}{c}\right)+2w\,l\right];$$

$$\text{H. P.} = \frac{\mu\,l}{33{,}000}\times\left[O\left(1+\frac{2\,w_1}{c}\right)+2\,w\,v\right].$$

Example.—Find the horsepower for an endless-rope system 5,000 ft. long for an output of 1,000 tons per day of 10 hours in a flat seam, the mine cars having a capacity of 2,000 lb. each and weighing 1,200 lb. each.

Assuming a speed of winding of 8 miles per hour or 704 ft. per minute, and for the coefficient of friction $\mu = \frac{1}{40}$,

$$T = \tfrac{1}{40}\left[\frac{5{,}000\times 3{,}333}{704}\left(1+\frac{2\times 1{,}200}{2{,}000}\right)+2\times 1.58\times 5{,}000\right] = 1{,}697, \text{ say } 1{,}700 \text{ lb.}$$

$$\text{H. P.} = \frac{5{,}000}{40\times 33{,}000}\left[3{,}333\left(1+\frac{2\times 1{,}200}{2{,}000}\right)+2\times 1.58\times 704\right] = 36.2 \text{ H. P. or,}$$

assuming an efficiency for the engine of 60%, $\frac{36.2}{.60} = 60$ H. P.

Inclined Roads.—The calculation of power for inclined roads is the same as that just given, excepting that the work due to lifting the coal through a height h must be added to that found by the previous formulas. If h equals the elevation due to the grade of the incline, the additional work of the engine due to hoisting the load from this elevation will be $O\,h$ and the total work per minute u will be

$$u = \mu\,l\left[O\left(1+\frac{2\,w_1}{c}\right)+2\,w\,v\right]+O\,h.$$

Example.—Assuming the same conditions as given above, and, in addition, a rise or elevation of 100 ft. in the entire length of the haulageway, we have $u = \frac{5{,}000}{40}\left[3{,}333\left(1+\frac{2\times 1{,}200}{2{,}000}\right)+2\times 1.58\times 704\right]+3{,}333\times 100$ $= 1{,}528{,}050$ ft.-lb. per minute $= 46.3$ H. P., or assuming an efficiency of 60% for the engine, $\frac{46.3}{.60} = 77$ H. P.

MOTOR HAULAGE.

Locomotive Haulage.—Wire-rope haulage is very efficient in headings, on heavy grades, and against large loads, but in crooked passages it entails great costs for renewals and repairs. When the grades do not exceed 5% for short distances and average 3% against, or for short distances 8% and 5% average in favor of loads, locomotives have been found the most economical form of haulage.

The chief advantages of locomotive over rope haulage are the flexibility of the system, it being able to serve any number of side tracks in various parts of the mine, and the closeness of the source of power to the point of application. In the event of an accident due to a car jumping the track, a broken wheel, etc., it often happens that a large number of cars are piled up before the man in charge outside the mine is signaled to stop, whereas with locomotive haulage the engineer or trip rider affords immediate relief.

In high seams and under favorable conditions, steam locomotives are very economical, but there is a limit to their use, for it is not well to fire while running in the mine when using bituminous coal; hence the length of trip is practically limited to the steam furnished with one firebox of fuel. On account of their many disadvantages and of the improvements in the methods of using other forms of energy, steam locomotives are fast going out of use and are being replaced by locomotives operated by compressed air and electricity, of which a number of types have been designed in recent years, and which have been very successful and have shown a marked efficiency over the mule.

Compressed-Air Haulage.—(See also page 194.) Compressed air is particularly applicable in gaseous mines, as it improves ventilation and is perfectly safe under all conditions. The great disadvantage in compressed-air haulage is the size of the locomotive.

Mr. H. K. Myers, of the Baldwin Locomotive Works, gives the following in regard to compressed-air haulage:

In order that compressed-air locomotives may be able to make a fair length of run, the tanks for storage purposes must necessarily be rather cumbersome, and constructed to carry high-storage pressures. In order that they may be designed correctly and get a minimum of storage for the maximum work expected, it is necessary to have a complete profile of the proposed haulage road, and to make a tabulated statement of the air consumption on the various grades, noting the "cut-off" necessary to produce the requisite tractive effort. By making a summation of these various amounts, and adding 20%, we will have the possible amount of air used in doing certain work as specified.

It is necessary, therefore, to provide storage on the locomotive for this amount of air at a much greater pressure than that used in the cylinders. In order that the locomotive may receive a quick charge at the stations specially provided for the purpose, it is necessary to have stationary storage of adequate pressure and capacity for the purpose.

At the present time, it is the custom to compress for the stationary storage to 800 lb., and to have the volume of this storage at least double the tank capacity of the locomotives comprising the system. This allows an equalized pressure in the locomotive storage of approximately 600 lb.

The following formula is useful in determining the capacity of stationary storage: $P' = \frac{pV + PX}{V + X}$; in which V = volume of storage on locomotive; X = volume of stationary storage desired; p = cylinder pressure; P = stationary storage pressure; and P' = locomotive storage pressure.

If the average time for each trip is 30 minutes, the compressor must be able to compress in that time to pressure P, the calculated amount of air required for one trip or series of trips for the various locomotives included in the haulage. In general, it is customary to extend extra-strong pipe into the mine and of such length and diameter as to have the required volume for the stationary storage. There are times however when it would be found more economical to arrange for tank storage either inside or outside the mine, but in general, especially when the mine is advancing, it is the better practice to install pipe storage since it increases the range of the locomotive as the workings advance.

The following table gives the various tractive efforts of different sizes of compressed-air locomotives, when working at 100 lb. cylinder pressure, and various cut-offs. If other pressures or strokes are used, the tractive efforts are directly proportionate. This table is calculated by means of the formula,

$$\text{tractive effort} = \frac{d^2 l x p}{D};$$

in which d = diameter of cylinder; D = diameter of driver; l = length of stroke; p = working pressure of the cylinders; and x = variable due to the various cut-offs.

TRACTIVE EFFORTS OF COMPRESSED-AIR LOCOMOTIVES.

Cylinder.		Diameter of Driver.	Weight on Driver.	Tractive Effort for Each 100-Lb. Cylinder Pressure at Various Cut-Offs.						
Diam. Inches.	Stroke. Inches.	Inches.	Pounds	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$
5	10	24	6,000	1,020	990	920	835	710	530	325
6	10	24	8,500	1,470	1,425	1,320	1,200	1,020	760	445
7	12	26	13,000	2,200	2,150	1,990	1,810	1,540	1,140	700
8	12	26	18,000	2,880	2,750	2,600	2,360	2,000	1,510	900
9	14	26	25,000	4,340	4,140	3,840	3,490	2,960	2,220	1,350
10	14	26	32,000	5,280	5,150	4,740	4,310	3,660	2,630	1,670
11	16	28	42,000	6,770	6,450	5,980	5,440	4,620	3,470	2,140
12	16	28	52,000	8,050	7,800	7,200	6,550	5,580	4,150	2,550

On account of certain losses due to radiation, etc. for cut-off at full length of stroke in steam practice, x is taken as .85. While cylinder surface acts as a detriment to the use of steam, it acts entirely opposite in the use of air, for the reason that, in the expansion of the air, very low temperatures are produced, and, with a maximum of cylinder surface exposed, we absorb a maximum of heat from the surrounding air, which virtually adds new energy to the air, thus acting as a reheater. Therefore in air practice, x is made .98 for full-stroke cut-off, with the others proportionately high. If simple-expansion cylinders are used, the working pressure should not exceed 130 lb., while, with compounds, one can easily use from 180 to 225 lb. with great economy. Where it is imperative to have a minimum-sized locomotive storage with a maximum run, this can be accomplished with compound locomotives. Originally, it was the custom to lag the cylinders as in steam practice, but now it is found advantageous to leave them bare and to corrugate both sides and ends so as to present a maximum surface to the surrounding atmosphere while running, thus absorbing new energy.

EXAMPLE.—It is desired to haul trips of 60 cars, empties weighing 2,000 lb. and loads 6,000 lb. each, over a track having the following profile, and with one charge of air. All grades are in favor of loads. (The following calculations have been made with the slide rule.)

PROFILE OF ROAD.

Grade.	Distance.	Grade.	Distance.	Grade.	Distance.
1.3%	800 ft.	0.30%	700 ft.	2.4%	400 ft.
2.0%	600 ft.	1.77%	1,025 ft.	3.5%	425 ft.
1.3%	800 ft.	0.90%	300 ft.	1.2%	320 ft.

The maximum grade being 3.5%, and the car friction in this case being 1%, the total resistance when ascending a 3.5% grade due to cars is, hence, 3.5% + 1% = 4.5%. Since it is desired to haul 60-car trips, and all grades are in favor of loads, it is only necessary to provide a locomotive capable of hauling 60 empties weighing 120,000 lb. up the above-mentioned grade. The drawbar pull necessary to do this is 4.5% of 120,000 lb. = 5,400 lb. In general, it will require a locomotive having a weight on drivers of 5 times the tractive effort desired if steel tires are used, as is the practice in the construction of air locomotives, and 6 times the tractive effort if cast-iron chilled wheels are used, as is the practice in electric locomotives. We will therefore assume the necessary weight of the locomotive to give the proper adhesion as 32,000 lb., and we calculate that the tractive effort necessary to haul itself up the 3.5% grade would be 3.5% + .5% = 4% (.5% covering the friction of the locomotive on the level) of 32,000 lb., or 1,280 lb., to which we add the necessary drawbar pull to haul the desired load, 1,280 + 5,400, and have a total tractive effort of 6,680, which is about the limit of a locomotive on dry rail with sand.

By consulting the table of tractive efforts of compressed-air locomotives, we see that, at 100 lb. working pressure, a 10″ × 14″, 26″ driver locomotive has a maximum tractive effort at $\frac{7}{8}$ cut-off, which is practically full stroke, of 5,280 lb., and by dividing $\frac{5280}{100}$ into our necessary tractive effort, we find that the necessary working pressure would be about 130 lb.

On this basis, we then make up the following table in order to ascertain the necessary air consumption:

GOING IN WITH EMPTIES.

Grade.	*Distance.*	*T. E.*	*Strokes.*	*Cut-Off.*	*Cu. In. Air Used.*
1.3	800′	3,375	120	$\frac{1}{4}$	126,000
2.0	600′	4,450	80	$\frac{1}{2}$	176,000
1.3	800′	3,375	120	$\frac{1}{4}$	126,000
0.3	700′	1,830	105	$\frac{1}{8}$	55,125
1.77	1,025′	4,100	150	$\frac{1}{2}$	315,000
0.9	300′	2,750	40	$\frac{1}{4}$	42,000
2.4	400′	5,075	60	$\frac{5}{8}$	157,500
3.5	425′	6,760	65	$\frac{7}{8}$	239,000
1.2	320′	2,220	50	$\frac{1}{4}$	52,500
		COMING OUT LOADED.*			
0.3	700′	2,600	105	$\frac{1}{4}$	110,000
					1,399,125
20% additional					279,825
Total					1,678,950 cu. in.

This equals 975 cu. ft. at 130 lb. pressure used in hauling the required loads on a single round trip. Since we should return to the starting point with 130 lb. in the locomotive storage, it is evident that the volume of the tanks shall allow for the use of 975 cu. ft. in addition to 1 volume at 130 lb.

Let V = volume of storage on locomotive; P' = pressure of storage on locomotive; p = working pressure; V' = volume at working pressure necessary to do the work required.

Then the product of the volume of the locomotive storage by its pressure must equal the sum of the volume necessary to do the work required multiplied by the working pressure, and the locomotive storage volume by the working pressure, thus,

$$P'V = pV + pV', \text{ or, } V = V'\frac{p}{P'-p}.$$

If $P' = 650$, then $\quad V = 975 \times \frac{130}{650-130} = 244$ cu. ft.

With one locomotive, making trips every 30 minutes, we must arrange for a compressor capable of compressing 975 cu. ft. at 130 lb. in this time. Since it is customary to rate compressors at their capacity in free air per minute, the above is equivalent to $\frac{975 \times 130}{14.7 \times 30} = 288$ cu. ft. free air per minute.

This must be compressed to 800 lb. in the compressor, and stored in stationary storage. If X is the volume of the stationary storage,

$$P' = \frac{pV + PX}{V + X}.$$

$$X = V\frac{P'-P}{P-P'}, \text{ or } X = 244 \times \frac{650-130}{800-650} = 846 \text{ cu. ft.}$$

The length of the haulage is 5,370 ft., hence the cross-section of the pipe necessary to furnish the requisite storage is $\frac{846}{5{,}370} = .157$ sq. ft.

From the following table, this would require a $5\frac{1}{2}''$ pipe, but for practical purposes it is possible that a 5″ pipe would be selected.

* Returning with loads, it is possible that there is only one grade that the trip will have to be hauled.

STANDARD STEAM AND EXTRA-STRONG PIPE USED FOR COMPRESSED-AIR HAULAGE PLANTS.

Trade Diameter. In.	Cu. Ft. in 1 Lineal Ft.	Lineal Ft. Necessary to Make 1 Cu. Ft.	Steam.		Extra Strong.		Trade Diameter. In.
			Thickness.	Weight per Ft.	Thickness.	Weight per Ft.	
2	.0218	45.41	.15	3.61	.22	5.02	2
$2\frac{1}{2}$	.0341	29.32	.20	5.74	.28	7.67	$2\frac{1}{2}$
3	.0491	20.36	.21	7.54	.30	10.20	3
$3\frac{1}{2}$	.0668	15.00	.22	9.00	.32	12.50	$3\frac{1}{2}$
4	.0873	11.52	.23	10.70	.34	15.00	4
$4\frac{1}{2}$	.1105	9.05	.24	12.30	.35	17.60	$4\frac{1}{2}$
5	.1364	7.33	.25	14.50	.37	20.50	5
$5\frac{1}{2}$	.1650	6.06	.26	16.40	.40	24.50	$5\frac{1}{2}$
6	.1963	5.10	.28	18.80	.43	28.60	6

From the following table we see that it would require $2.88 \times 32.5 = 93.6$ H. P.; hence, we would be compelled to arrange for a boiler capacity of practically 100 H. P., provided we used a three-stage compressor, as is the general custom.

HORSEPOWER NECESSARY TO COMPRESS 100 CU. FT. OF FREE AIR TO VARIOUS PRESSURES AND WITH TWO-, THREE-, AND FOUR-STAGE COMPRESSORS.

Gauge Pressure.	Horsepower Necessary.			Gauge Pressure.	Horsepower Necessary.		
	Two-Stage.	Three-Stage.	Four-Stage.		Two-Stage.	Three-Stage.	Four-Stage.
100	15.7	15.2	14.2	900	36.3	33.7	31.0
200	21.2	20.3	18.8	1,000	37.8	34.9	31.8
300	24.5	23.1	21.8	1,200	39.7	36.5	33.4
400	27.7	25.9	24.0	1,400	41.3	37.9	34.5
500	29.4	27.7	25.9	1,600	43.0	39.4	35.6
600	31.6	29.5	27.4	1,800	44.5	40.5	36.7
700	33.4	31.2	28.9	2,000	45.4	41.6	37.8
800	34.9	32.5	30.1	2,500		43.0	39.0

Electric Haulage.—Mr. H. K. Myers says in regard to mine haulage by electricity: In general, it costs from 6 to 10 cents per ton to deliver coal from face of workings to shaft, slope, or tipple, where the haul is 1 mile and the tracks approximately level; yet I know three mines that at present haul from parting with the trolley system, the miner delivering from face of room, making an average round trip of 9,000 ft., at a total cost of 1 cent per ton. These mines have never had a mule in them, and it would be almost an impossibility to introduce them, for the reason that the seam is of such thickness that the clearance between tie and roof is only about 4 ft. Since the advent of the electric-mining locomotive, there has been a change in the mine wagons universally used. Formerly it was customary to find as much as 60 lb. per ton car resistance on the level, while at present it is as low as 15 lb.

In dimensioning mining locomotives, it is customary to make the weight from 6 to 8 times the necessary tractive effort, dependent entirely on the nature of the work. If the work is constant and a maximum, then the weight will be only 6 times the torque of the motors, while if the work is intermittent with a short-time maximum tractive effort, then the factor will be 8. The weight of an electric locomotive running at a speed of 6 to

8 miles per hour with intermittent load may also be expressed on a basis of 400 lb. for each rated horsepower of the motor, and the weight should be 8 times the rated drawbar pull, regardless of speed. For continuous work, these weights should be decreased 25%.

DRAWBAR PULL ON VARIOUS GRADES FOR DIFFERENT SIZED LOCOMOTIVES.

Horse-power.	Weight.	Grades.						
		Level.	1%	2%	3%	4%	5%	6%
10	4,000	500	460	420	380	340	300	260
20	8,000	1,000	920	840	760	680	600	520
30	12,000	1,500	1,380	1,260	1,140	1,020	900	780
50	20,000	2,500	2,300	2,100	1,900	1,700	1,500	1,300
70	28,000	3,500	3,220	2,940	2,660	2,380	2,100	1,820
100	40,000	5,000	4,600	4,200	3,800	3,400	3,000	2,600

In mines it is found that the friction between wheel and rail is less than on the surface, due to dampness and powdered coal on the rail. The tractive efforts with chilled wheels is usually considered $\frac{1}{8}$ of the weight. The table on page 408 and diagram on page 409 give hauling capacities of locomotives in tons of 2,000 lb.

For maximum continuous work, it is necessary to have a grade such that the efforts to haul the same number of empty wagons as loaded are equal. With the car resistance considered 1% and the loaded cars weighing 3 times as much as the empties, this is found to be $\frac{1}{2}$ of 1%. The most critical point in the designing of mining locomotives is to make the limiting dimensions a minimum. The demands for various dimensions are wonderful. The headings in mines are never of more generous proportions than really necessary, and all clearances a minimum. The minimum dimensions for mining locomotives are as small as 2 ft. for wheel base, 8 ft. for length over all, and 3 ft. width. Scarcely two orders carry the same dimensions, and it is impossible to have any kind of a standard. In consequence of this, it is necessary to have a great variety of motors suitable for gauges as narrow as 18 in. and for wheels as small as 20 in. in diameter. With such a variety, it becomes possible to construct a locomotive weighing 40,000 lb. on 3′ gauge, having the width over all 62 in., height 35 in., and length 12 ft. In construction, it is necessary to have the most modern form of motors and the most rigid mechanical construction.

The motors now used are of the best possible construction and efficiency. They are of the slow-speed street-car type, 6 to 8 miles per hour winding, and range in size from 4 to 50 H. P. It is customary to use the rheostatic type of controller for mining locomotives, on account of its small dimensions and apparent efficiency for this class of work, but it is doubtless but a short time until a very compact form of series-parallel type will be devised. On account of the use of this rheostatic controller, it becomes necessary to provide for large diverter capacity, and since the locomotive is designed for the maximum tractive effort, it is hardly ever possible to run without resistance and, hence, a large amount of current must be dispersed with the consequent heating. If the motors are overloaded, they heat rapidly, this heating varying as the square of the current. A motor that has a rating of 40 amperes for regular work, if worked for 3 minutes at 100 amperes, should not be subjected to such a strain oftener than once in $18\frac{3}{4}$ minutes, as shown by the following equation:

$$40^2 \times x = 3 \times 100^2; \; x = 18\tfrac{3}{4} \text{ minutes.}$$

Using the same problem given under compressed-air locomotives, in which the maximum tractive effort was 6,760 lb., we find from the table of drawbar pulls that a locomotive equipped with two 50 H. P. motors (equals 100 H. P.) will carry the load with an overload, these motors being rated for continuous work at approximately 32 amperes of 500 volts.

Using the formula $\sqrt{\frac{\Sigma ta^2}{T}} = 64$, in which t = various times at which

various amounts a of current are used on the corresponding grades, Σ the summation of the items $t\,a^2$ calculated for each section or grade, and T = total time that should be taken for each trip, we calculate the following table:

Grade.	Dist.	T. E.	Time. Minutes.	Amperes.	$t\,a^2$
					Empties.
1.30	800	3,375	1.5	114	19,600
2.00	600	4,450	1.1	134	19,900
1.30	800	3,375	1.5	114	19,600
.30	700	1,830	1.3	74	7,100
1.77	1,025	4,100	2.0	128	32,800
.90	300	2,750	.6	100	6,000
2.40	400	5,075	.8	148	17,300
3.50	425	6,760	.8	182	26,500
1.20	320	2,220	.6	86	4,400
					Loads.
.30	700	2,600	1.3	96	13,900
					$167,100 = \Sigma\,t\,a^2$

$$\sqrt{\frac{167,100}{T}} = 64; \quad 4,096\,T = 167,100; \quad T = 40.$$

By this means we can make 60-car trips every 40 minutes without injury to the motors, based upon a speed of 6 miles per hour. (See also page 215.)

Speed of haulage depends on the system of haulage used and on the condition of the haulage road. The law in Pennsylvania provides for a speed of haulage not over 6 miles per hour, and this is the speed at which electric and

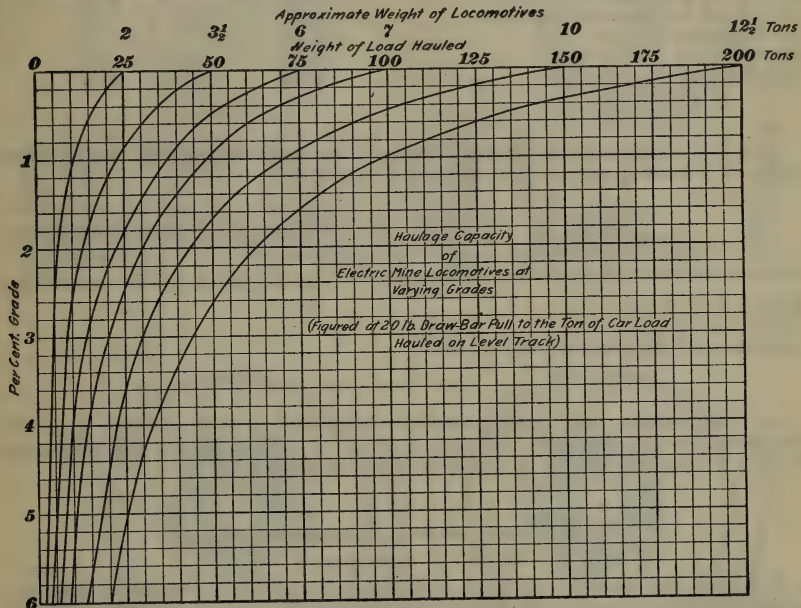
HAULING CAPACITY OF ELECTRIC LOCOMOTIVES.

Horsepower.	Weight.	Drawbar Pull on Level.	Frictional Car Resistance per Ton on Level.	Grades. Level.	½%	1%	1½%	2%	2½%	3%	3½%	4%	5%	6%
10	4,000	500	20	23	15	10	8	6.3	5.2	4.2	3.5	3.0	2.2	1.6
			30	15	11	8.4	6.7	5.4	4.5	3.8	3.2	2.7	2.0	1.5
			40	12	9	7	5.7	4.7	4.0	3.4	3.0	2.5	1.8	1.4
20	8,000	1,000	20	46	29	21	16	13	10.3	8.4	7.1	6.0	4.3	3.1
			30	31	22	17	13	11	9	7.5	6.4	5.4	4.0	3.0
			40	23	18	14	11	9.5	8	6.8	5.9	5.0	3.7	2.8
30	12,000	1,500	20	69	44	32	24	19	15	13	10.7	9.0	6.5	4.7
			30	43	33	25	20	16	13	11	9.6	8.2	6.0	4.4
			40	34	26	21	17	14	12	10	8.8	7.5	5.6	4.1
50	20,000	2,500	20	115	73	52	40	32	26	21	18	15	11	7.9
			30	77	55	42	33	27	22	19	16	14	10	7.3
			40	58	44	35	29	24	20	17	15	13	9.3	6.8
70	28,000	3,500	20	161	103	74	56	44	36	30	25	21	15	11
			30	107	77	59	47	38	31	26	22	19	14	10
			40	81	61	50	40	33	28	24	20	18	13	9.6
100	40,000	5,000	20	230	147	105	80	63	52	42	36	30	22	16
			30	153	110	84	67	54	45	38	32	27	20	15
			40	115	88	70	57	47	40	34	29	25	19	14

compressed-air haulages are usually calculated and at which loaded trips are usually run. Empty trips are usually run at a slightly higher speed.

The speed for tail-rope haulage is given by three prominent makers of such plants, as follows: (*a*) 600 to 700 ft. per minute; (*b*) 8 to 10 miles per hour; (*c*) 6 to 8 miles per hour.

The speed for endless-rope haulage is given by the same makers as (*a*) 140 to 150 ft. per minute; (*b*) 1 to 2 miles per hour; (*c*) 150 to 200 ft. per minute. A slow speed for endless rope is to be preferred as being much more economical in the wear of the rope and cars, and many prefer a single-car system to a trip system, thus doing away with the trip rider. By handling the cars singly or even in trains of two and at a slow speed, the load can be picked up without any slippage of the rope through the grips; while if trains of from 12 to 25 cars are used, with the rope traveling 3 to 3½ miles per hour, it is impossible to pick up the load without having the rope slip



through the grip, thus heating the rope and cutting it. The slow-speed, single-car or small-train, system requires more cars, but this is counterbalanced by the life of the cars and rope. Those that have tried both systems prefer the slow-speed small trip to the high-speed large trip.

It has been found in general practice that the maximum pulling power of a mule as well as a locomotive is, approximately, one-fifth its weight, or, in other words, a locomotive will pull as much as the same weight of mules will pull, and at a speed about three times as great.

Cost of Haulage.—So much depends on local considerations that it is difficult to give costs of haulage that will be of service. Mule haulage has been given as costing, under different conditions, 5.74 cents and 7.92 cents per ton-mile, and in other locations 2.35 cents, 2.95 cents, and 7.15 cents per ton of coal hauled.

The Berwind-White Coal Mining Co., at Windber, Pa., uses 30 electric locomotives at various mines, which average, approximately, 400 tons per day of 9 hours, per locomotive, over an average haul of 2 miles for the round trip. The approximate cost for operating one of these locomotives, including the wages of motorman, trip rider, and proportion of power-house expense, is about $6.00 per day, or 1½ cents per ton of coal haul per mile. If the total load, including weight of cars, is considered, it figures ¾ of 1 cent per ton per mile. These figures do not, however, include grades, which is an important factor in equating costs per ton per mile. In these mines there are no mules

whatever, the locomotives distributing the empty cars to room partings, for the men to push to the face. If the haul is done between side tracks and under similar grade conditions, the same locomotives could easily handle 1,000 to 1,200 cars per day.

Mr. F. J. Platt, of Scranton, Pa., gives the following comparative costs of electric and mule haulage per ton of coal hauled and under approximately the same conditions in the same mine:

Name of Mine.	Mule Haulage. Cents.	Electric Haulage. Cents.
Green Ridge Colliery	7.15	2.76
New York & Scranton Coal Co	6.58	2.62
New York & Scranton Coal Co	2.35	1.07
Mt. Pleasant Colliery	2.95	1.27
Hillside Coal & Iron Co.	10.77	4.56
Hillside Coal & Iron Co.	9.10	4.65

The following costs of electric haulage, per ton of material hauled, are given in the catalogue of the General Electric Co.:

Name of Mine.	Mule Haulage. Cents.	Electric Haulage. Cents.
Wythe Lead & Zinc Co	10	2.56
Blossburg Coal Co.		7.9
Cleveland-Cliffs Iron Co. ('94, '95, '96)		3.9, 4.5, 4.8

At Carbondale, Pa., compressed-air locomotives have hauled coal for 1.5 cents per ton-mile, at Mill Creek, Pa., for 3.77 cents per ton-mile, and at Glen Lyon, Pa., for 1.89 to 1.93 cents per ton-mile.

THIRD-RAIL MINE LOCOMOTIVES.

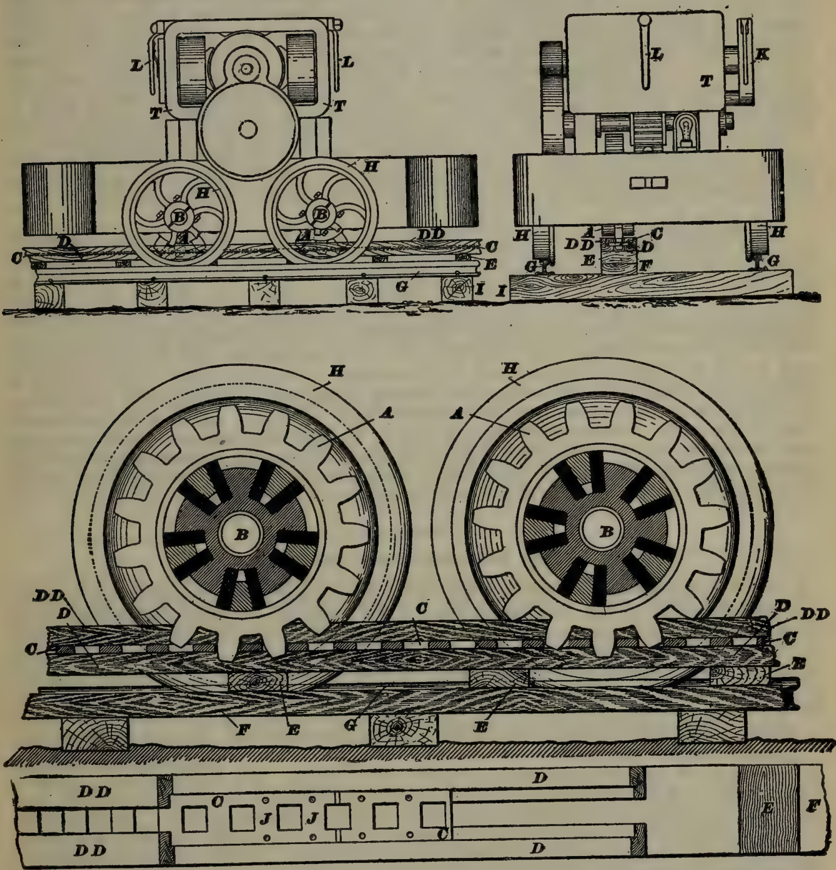
By W. L. Affelder.*

Traction locomotives have overcome practically every obstacle that has appeared in their path except that of grade. No conservative manufacturer will recommend a traction locomotive for a haulage in which the grade against the loaded trips exceeds 5 per cent., and the more conservative place 4 per cent. as the practical limit. A traction locomotive will work successfully on considerably steeper grades when the grades are short and all of a large trip will not be on the grade at the same time, but where a grade of over 4 per cent. is continuous over a considerable distance, some other system of mechanical haulage should be adopted. This fact led several companies into experimenting on electric haulage in which tractive force due to the weight of the locomotive would not be a factor, and in which friction and gravity alone would have to be overcome.

In 1899, the Morgan Electric Machine Co. placed their first third-and-traction-rail locomotive, or so-called "sprocket" locomotive, in the Star City, Ind., mine of the Harder & Hafer Co., of Chicago. This system, as developed, combines the flexibility of the trolley-traction system and the advantages of the wire-rope systems in surmounting grades. The third rail is generally placed 5 inches to the right of the center of the track. There are three sizes of third rail—standard, heavy, and special, and the component parts of each are made in 16-foot lengths. The standard size will be described. A $6\frac{1}{2}'' \times 1\frac{1}{2}''$ white-pine bottom stringer *F* is securely spiked to the ties, which are first trimmed, if necessary, to receive it. On this stringer are spiked, at intervals of about 18 inches, pine blocks *E* of

*See "Mines and Minerals," March, 1904.

sufficient thickness to bring the height of the completed third rail 4 inches above the height of the steel rails. Two longitudinal pine strips *D*, each $2\frac{1}{2}$ in. $\times$ $1\frac{1}{2}$ in., are spiked to the blocks, leaving a $1\frac{1}{2}$-in. slot between them. They are trimmed on top in such a way as to allow the iron track *C*, which is 4 in. wide and $\frac{5}{8}$-in. thick, to be partially countersunk. This track consists of a flat bar of iron with $1\frac{5}{8}$-in. square holes punched through it at intervals of the same distance. It is made continuous by means of perforated fish plates *J* that are securely bolted to the ends of the two bars at a joint. Two pine strips *DD*, which are similar to strips *D* except that they are trimmed on the lower side to cover the iron rail, are laid on the strips *D* and fastened to them with 4-in. spikes. By means of an insulated copper cable, which is connected with the iron bar, the positive electric current is



introduced into the third rail. The wooden portion of the rail acts both as a carrier of the iron bar or rack and as a medium for insulating it. The negative current is carried by the bonded steel rails.

The locomotives are made in two standard sizes: one having an 80-H.P. motor and the other two motors of the same kind.

On each of the two axles *B* are two track wheels *H* and one steel sprocket *A* with its accompanying gear. The track wheels are tight on the axles, but the sprocket and gear are loose, the sprocket being insulated both from the axle and from the gear by means of maple blocks, shown in solid black in the figure. The teeth of the two sprocket wheels, which are geared to run in unison, run in the slot between the two wooden strips *D D* and *D* of the

third rail and engage the iron rail *C*. In coming in contact with the charged iron rail, they take up the current, and through the agency of copper contact springs that rub against them, impart the current to the motor or motors. In revolving, the motor drives the sprockets, and as the construction of the third rail is such as to make it absolutely rigid, the movement of the sprockets in the perforated iron track produces motion of the locomotive. As all transmission of power is through the cut-steel gear-wheels, loss of power is entirely eliminated.

The following advantages are claimed for this system: The full power of the third-rail locomotive—weighing only 6,000 lb.—is available at all times regardless of the grades, within limits, or slippery character of the track surface. The third rail can be extended easily and cheaply by the track layers as the regular track is extended. There is little liability of explosions being caused by the electric current, as the conductor is close to the floor; and from this same line power can be taken off at any point to light the mine and to run machinery. No sand, trolley pole, or trolley wire are required; and men and animals are safe, as it is practically impossible for them to accidentally come in contact with the electric current. Also, heavy falls of roof will not injure the third rail. Moreover, in this system, only a comparatively small weight has to be moved, thus saving in power and wear.

A modification of the above-described system is manufactured by the Morgan Electric Machine Co., consisting of a combination of a complete trolley traction locomotive with the third-rail feature for use on grades.

Gathering locomotives are used to take the cars from the rooms. They are similar in their general construction to the ordinary traction locomotive but are shorter and lower. In traveling along the entries the locomotive obtains its power by means of a regular trolley attachment, but when leaving an entry to go into a room the trolley pole is fastened down and a flexible insulated cable is hooked upon the trolley wire and upon the track. The current returns through the bonded rails in rooms where steel rails are used, and when wooden rails are used in the rooms a double cable like that on a mining machine is used, one cable being attached to the trolley wire upon the entry and the other to the ground wire or entry rail. The reel upon which the cable winds acts automatically to keep the cable taut in winding and unwinding. It is operated by chains and sprocket wheels or by friction plates. Several makes of gathering locomotives are now being operated successfully, both in anthracite and bituminous mines.

MINE ROADS AND TRACKS.

Underground or mine-car tracks should be solidly laid on good sills, resting on the solid floor of the mine. They should be well ballasted, and should have good clean gutters on the lower side of the entry, so that the rails may be protected as much as possible from the action of the mine water. Much of the following data, on mine roads is based on an article on "Mine Roads," by Mr. H. L. Auchmuty, "Mines and Minerals," March, 1900.

Grade.—The grades depend entirely on circumstances, but, when possible, the grade should be in favor of the load, and should be at least 5 in. in 100 ft. to insure flow in the gutters alongside the track. On main roads, where wagons having a capacity of 1.5 to 2.5 tons are hauled by animal power, the grades should not exceed 1% to 2% in favor of the loaded wagon. Such a rate of grade provides for an easy return haul of the empty trip without wearing out the stock, and likewise insures good drainage. With grades under 1%, unless the ditches are kept perfectly clean, the drainage is apt to be sluggish, and then, in low places, we are sure to find a wet and muddy track, which is a great source of waste energy.

Where hauling is done by locomotives, whether by compressed air or steam, the adverse grades should not be over 1.5% to 2.5% if it can possibly be avoided. When gradients are heavy, too great a percentage of the tractive power of the locomotive is consumed in drawing itself up the grade.

Ties should be spaced about 2 ft. apart, center to center, making 15 to a 30′ rail. The rail should be well spiked to the ties with four spikes to each tie, the joint between two rails on one side of the track being located about midway between two joints on the opposite rail. Care should be taken in locating the spikes that they are not all in the center of the tie, thereby

causing a tendency to split the same. It is best to place them each side of the center with two spikes between the rails, on one side, and the two spikes on the outside of the rail on the other side of the center of the tie. With the spikes so located, there is no tendency for the tie to slide, as there is if an outside and inside spike are on the same side of the center of the tie. Ties having a 5 in. face and 4 in. deep by $5\frac{1}{2}$ ft. in length should be used for the ordinary sizes of rail, i. e., 16 lb. to 20 lb., and, in general, the thickness should be sufficiently great that the spike does not pass entirely through the tie, as then its holding power is greatly diminished. On haulage tracks where 35-lb. to 40-lb. rail is used, the ties should be at least 5 in. deep and have a face of 6 in., the ties ordinarily used for lighter sizes of rails being entirely too thin for rails of this weight, as a larger spike than the ordinary 3 in. $\times \frac{3}{8}$ in. is required to securely hold the rails to place. The ends of the ties should be lined up along one side of the track, so that they are all the same distance from the rail, and, with each tie placed at right angles to the rail as it should be, we have a well-spaced, neat-looking track, which, when well tamped with the ballast, is perfectly solid. On curves, the ties should be laid so as to form radii of the curves of the track.

Rails.—The weight of rail to be chosen in any individual case depends entirely on the weight of wagons used, and the motive power. For wagons whose capacity is about 1.5 tons, the weight of rail, when the motive power is live stock, should not be less than 16 lb. per yd., while for wagons having a capacity of 2 tons or over, a 20-lb. rail should be used. There is no economy in using a very light rail, as the base is gradually eaten away by the mine water when it comes in contact with the metal, and in the case of a heavy section of rail, it will be much longer before the rail becomes weakened.

On main roads, where haulage machinery of one kind or another is used, the weight of rail for 2-ton wagons should be from 25 lb. to 35 lb. per yd., and on steep slopes as high as 40 lb. per yd.

In the case of locomotive haulage, authorities claim that the weight of rail should be regulated by allowing 1 ton for each driver for each 10 lb. weight of rail per yd.

Gauge.—The gauge of the track in coal mines should not be less than 30 in. nor more than 48 in. A mean between these two, or a gauge of from 38 in. to 42 in. is desirable, because it combines, to a certain extent, the advantages claimed for the extremes. The advocates of broad gauges believe that the greater stability of the track and the consequent reduction in haulage expenses, the increased capacity of the broad-gauged mine cars, the reduction in the outlay for rolling stock, and for repairs to the same, more than equal the disadvantages of broad as compared to the narrow gauges.

Advocates of the narrow gauges think that the ease of hauling around sharp curves, the reduction in cost of construction, and the use of mine cars with inside wheels, are advantages greater than those advanced by the advocates of the broad gauges. An allowance of about $\frac{1}{2}$ in. should always be made between the wheel gauge and the track gauge. By so doing, the resistance to hauling is greatly overcome, and there is no binding of the wagons on the track, hence a less likelihood of having derailed wagons. With an average running wagon, there is a resistance of 15 to 20 lb. per ton tractive force on a level track, which would be equal to the resistance occasioned by a grade of .75% to 1%, and with wagons that bind on the track, this resistance is greatly increased.

Curves should be of as large a radius as possible, and never, if possible, of less radius than 25 ft. The resistance of curves is very considerable. The less the radius of the curve, and the greater the length of the curved track occupied by the trip, or train, the greater the resistance. The length of wheel bases of the cars, the condition of rolling stock and of the track, and the rate of speed, all influence the resistance, and there is no formula that will apply to all cases. In practice on surface railroads, engineers compensate for curves on grades at the rate of $\frac{3}{100}$ ft. in each hundred feet for each degree of curvature, the grade being stated in feet per hundred. In mine work, this compensation is not made, as the gain will not pay for the labor that must necessarily be employed to do work in a thoroughly scientific manner.

Sharper curves can be used on narrow-gauge roads than on broad-gauge roads, because the difference in length of the inner and outer rails on curves on the same degree is not quite so great, and also because the wheel bases of cars are less. The track should be spread about $\frac{1}{4}$ in. on easy curves, and

on very short curves about 1 in., or as much as the tread of the wheels will permit. A good rule is to widen the track $\frac{1}{16}$ in. for each $2\frac{1}{2}°$ of curvature. Short and irregular curves are to be avoided whenever possible, as they increase the load and are destructive to rails and rolling stock. When a sharp curve is necessary, the rail should be bent to the right curvature by a portable rail bender, or by a jack and clamps.

To Bend Rails to Proper Arc for Any Radius.—Rails are usually 30 ft. long, and the most convenient chord to use in bending mine rails is 10 ft.

Then, having the radius and chord, we find the rise of middle ordinate by squaring the radius, and from it take the square of $\frac{1}{2}$ the chord. Extract the square root of the remainder and subtract it from the radius; the result will be the rise of the middle ordinate. Thus, having a radius of 30 ft. and a chord of 10 ft., the middle ordinate will be

$$30 - \sqrt{30^2 - 5^2}, \text{ or } 0.42 \text{ ft.}$$

Rail Elevation.—In elevating rails on curves, consider whether the hauling is to be done by a rope, or by a locomotive, or electric motor. For either of the latter, elevate the rail on the outside of the curve; but for the first, elevate the inner rail, since as the power is applied by a long flexible rope, there is always a tendency for both rope and wagons to take the long chord of the curve as soon as the point of curve is reached. On slope haulages, operated by a single rope, when the weight of the wagons traveling on the grade of the slope is sufficient to draw the rope off the hoisting drum, the rails on curves should be elevated on the outside, the effect then being similar to that of a locomotive, i. e., the centrifugal force tends to throw the wagon to the outside of the track. In such cases, the elevation should be moderate so as not to interfere with the trip when drawn out again by the rope—the opposite effect being then experienced. On an 18° curve (319 ft. radius), an elevation of 2 in. or 3 in. in the outer rail, where the haulage was by slope rope, has never given any trouble in operating. In general, the elevation of rail necessary for different degrees of curvature for a 42″ track gauge should be made in accordance with the following table:

TABLE OF ELEVATIONS.

For outer rail of curves for a speed of 10 to 15 miles per hour and a gauge of track of 42 in. for locomotives; or for slope haulages where cars run down grade by gravity.

Degree of Curve.	Radius of Curve (Ft.).	Elevation of Outer Rail (In.).	Degree of Curve.	Radius of Curve (Ft.).	Elevation of Outer Rail (In.).
1	5,729.6	$\frac{1}{8}$	10.0	573.7	$1\frac{1}{8}$
2	2,864.9	$\frac{1}{4}$	12.0	478.3	$1\frac{5}{16}$
3	1,910.1	$\frac{5}{16}$	15.0	383.1	$1\frac{5}{8}$
4	1,432.7	$\frac{7}{16}$	18.0	319.6	$1\frac{15}{16}$
5	1,146.3	$\frac{9}{16}$	20.0	287.9	$2\frac{3}{16}$
6	955.4	$\frac{11}{16}$	57.3	100.0	$4\frac{1}{2}$
7	819.0	$\frac{13}{16}$	95.5	60.0	$4\frac{1}{2}$
8	716.8	$\frac{7}{8}$	114.6	50.0	$4\frac{1}{2}$
9	637.3	1			

No elevation should be over $4\frac{1}{2}$ in., which would be equivalent to an elevation of 6 in. for standard track gauge of 4 ft. 9 in., the latter being considered as the maximum for standard gauge.

Rollers.—The rollers on level tracks should not be more than about 20 ft. apart to properly carry the rope, and on gravity slopes where the lower end of the slope gradually flattens off, the distance between rollers should not be more than 12 to 15 ft., as this spacing allows the trip of wagons to run much farther, by keeping the rope well off the ties, than if they are farther apart, thereby not supporting the rope, and causing a great amount of friction between the rope and the ties. With tracks in fair shape and rollers 12 to 15 ft. apart, the resistance, due to the rope in running empty wagons down grades varying from 3.8% to 6.2%, varied from 6% to 15% of the weight of ropes by actual trial.

Switches.—The switch, or *latch*, most commonly used in mines is shown in Fig. 7. When the branch or siding is in constant use, an ordinary railway frog is substituted for the bar *b*. The latches *a*, *a* are wedge-shaped bars of iron (made as high as the rail) with an eye in the thick end. They are sometimes connected together by a rod attached to a lever so that they may both be moved at once from the side of the track, or by a person situated some distance away. This switch is made self-closing or automatic whenever it is necessary to run all the cars off at the branch (the switch then being used only to admit cars to the main track) by attaching the latches through a bar or lever to a metallic spring, a stick of some elastic wood, or a counter weight, to pull them back into a certain position whenever they have been pushed to one side or the other by the passage of a car on the main track. Figs. 10, 11, 12, and 13 show some of the applications of these spring latches or automatic switches.

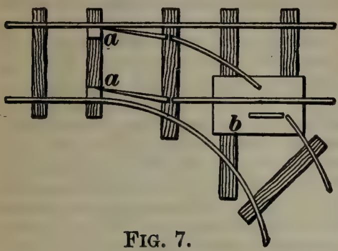


FIG. 7.

A modification of this switch is shown in Fig. 8, which represents a form of double switch. These latches are set by the drivers, who kick them over and drop a small square of plate iron between them to hold them in place This switch costs more than the other style and is better adapted to outside roads than to inside roads.

The ordinary movable rail switch in common use on all surface railways is sometimes used in mine roads. It is commonly used in slopes arranged as shown by Fig. 12, to replace latches set by the car, and is also largely used in outside roads.

For crossings, ordinary railway frogs and grade crossings are sometimes used, as is also a small turntable, which then answers two purposes. More frequently the plan shown in Fig. 9, in which four movable bars are thrown across the main track whenever the other road is to be used, is adopted.

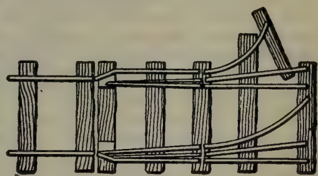


FIG. 8.

The subordinate road is built from $1\frac{1}{2}$ to 2 in. higher than the main road, to allow the bars to clear the main-track rails.

Turnouts.—On gangways or headings used as main haulage roads, turnouts should be constructed at convenient intervals to allow the loaded and empty trips to pass. These turnouts should be long enough to accommodate from 5 or 6 up to 15 or 20 cars. The switches at each end may be made self-acting so that the empty trip, coming in, is thrown on the turnout, and in running out on the main track at the other end, the loaded cars open the switch, which immediately closes.

As there is constant trouble with self-setting switches, either from small fragments of coal or slate clogging them up, or from insufficient power of the spring to move them, they are viewed with disfavor by many mine managers, who do not care to use them under any conditions.

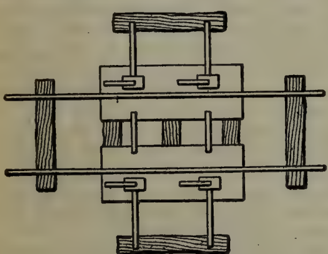


FIG. 9.

Slope Bottoms.—At the foot of a slope, or at the landing on any lift, the gangway is widened out to accommodate at least two tracks—one for the empty and one for the loaded cars. The empty track should be on the upper side of the gangway, or that side nearer the floor of the seam, and the loaded track on that side of the gangway nearer the roof of the seam.

An arrangement of tracks often used is shown in Fig. 10. At a distance of 40 or 50 ft. above the gangway, the slope is widened out to accommodate the branch leading into the gangway loaded track. This branch descends with a gradually lessening inclination until nearly at the level of the gangway it turns into the main loaded track. A short distance above the gangway.

a bridge or door is placed, which, when closed, forms a latch by which the empty cars are taken off the slope. The empty track is about 6 ft. higher than the loaded track, and is carried over it on a trestle. The illustration in Fig. 10 shows the plan as arranged for a single slope, or one side only of a slope taking the coal from both directions. When coal is being raised from this lift, the bridge is closed; the empty car comes down and is run off over the bridge; the car is unhooked from the rope, and the chain and hook attached to the rope are thrown down to the branch below on which a loaded car is standing; the loaded car is attached, the signal given, the car ascends to the main track on the slope, opening the switch—or the switch may be set each time by the bottom men, by a lever at the bottom of the branch. This plan can only be economically applied in thick seams, as the height necessary to allow one track to cross the other on a trestle cannot be obtained in seams of moderate thickness without taking down a large amount of top.

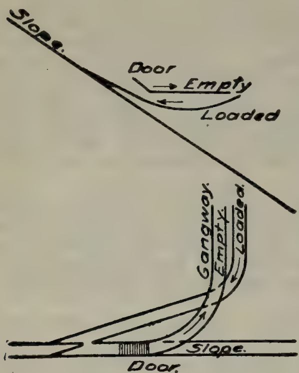


FIG. 10.

A more simple plan, which dispenses with the bridge, is often used. The branch is laid off, as shown by Fig. 10, but, near the point where it enters the gangway, a switch opening into the empty track is placed. By this arrangement, the tracks cannot be as well arranged for handling the cars by gravity as in the former plan, in which the empty cars when detached from the rope run by gravity into the empty siding, and the loaded cars descend by gravity around the curve to the foot of the branch, where they lie ready to be attached to the rope.

When the pitch of the slope is so steep that the coal or ore falls out of the cars, during hoisting a gunboat is used or the cars are raised on a slope carriage—in either case, the arrangement of the tracks at lift landings is entirely different. With either a gunboat or a slope carriage, the arrangement of tracks on the slope is the same; but, in the former case, a connection between the slope and gangway tracks is often advisable. When a gunboat is used, the gangway tracks run direct to the slope, and a tipple, or dump, is placed on each side to dump the mine cars over the gunboat; but when the cars are raised on a slope carriage, the gangway tracks run direct (at right angles) to the slope, to carry the car to the cage or carriage. The floor of the cage is horizontal, and has a track on it that fits on the end of the gangway track when the carriage is at the bottom, and this track is arranged with stops similar to those on cages used in shafts.

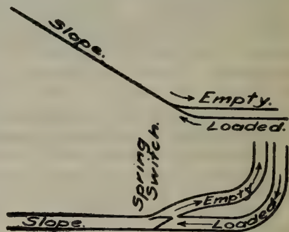


FIG. 11.

Another common arrangement of tracks at the bottom of a slope is shown in Fig. 11. A branch is made by widening the slope out near the bottom, and this, being a few feet higher than the main track, is used to run off the empties by gravity. The loaded cars run in by gravity around the curve to the foot of the slope in position to be attached to the rope.

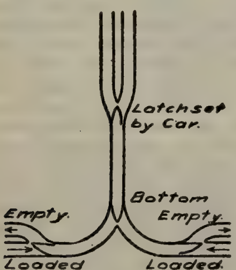


FIG. 12.

In ascending, the loaded car forces its way through the switch, or the switch may be set by a lever located at the foot of the slope. When the empty car descends, it runs in on the branch, where the chain is unhooked and thrown over in front of the loaded car, and runs around the curve into the gangway by gravity.

It will be observed that in this plan the loaded car (and consequently the

bottom men) stands on the track in line with the slope, and is in danger from any objects falling down the slope, or from the breakage of the rope or couplings; but this can be obviated by making the bottom on the curve. The illustration in Fig. 11 shows only one side of the slope; the other side is, of course, similar.

All these plans necessitate the location of that part of the gangway near the slope, in the upper benches of the coal or near the top rock. The gangway is then curved gently around toward the floor, so that, when it has been driven far enough to leave a sufficiently thick pillar, the bottom bench is reached and the gangway is then driven along the bottom rock.

A very different bottom arrangement is shown by Fig. 12, which also represents a plan frequently adopted on surface planes. The two slope tracks are merged into one a short distance from the bottom of the slope, and on the opposite sides of the bottom two tracks curve around into the gangway on opposite sides of the slope. As these branches curve into the main gangway tracks, a switch sends off a side track for the empty cars. The switch on the slope is either set by the car—and this can be done because the next loaded goes up on the same side on which the last empty descended—or by a lever located at the bottom.

It will at once be seen that in this plan no opportunity is afforded of handling the cars by gravity. The curved branches are made nearly level, and the momentum of the descending car, if quickly detached, is often sufficient to carry it partly or wholly around the curve, even against a slight

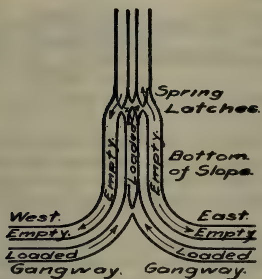


FIG. 13.

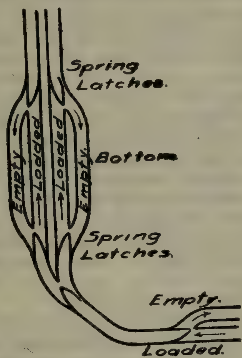


FIG. 14.

adverse grade. The disadvantage above noted of having the bottom in direct line with the slope (where there is danger from breakage and falling material) also obtains in this plan.

In the plan shown by Fig. 13, the grades may be so arranged that the cars can be entirely handled by gravity. The latches on the main-slope track may be closed automatically by a spring or weight, the loaded car running through them in its ascent on the slope, or both sets may be operated by a single lever at the bottom. The switch at the upper end of the central track (loaded) is set by a hand lever. All three sets may be linked together, so that they can all be properly set by a single lever. Reference to Fig. 11 will show that this is only a modification of that method. It requires space at the bottom for only three tracks, while Fig. 13 requires width to accommodate four tracks, and is objectionable because it is more complicated. The extra set of latches at the top of the central track, and the curvature of both main tracks into this central one, must inevitably cause much trouble and delay from cars jumping the track at this point.

The plan shown in Fig. 14 is open to many of the objections pertaining to some of those already described, and which need not be reiterated here. It can only be employed in thick seams, or in seams of moderate thickness lying at a slight angle or dip.

In planning the arrangement of tracks on a slope, it is advisable to place as few switches as possible on the slope itself, to keep the main track

unbroken, to make the tracks as straight as possible, to have nothing standing at the bottom in direct line with the slope tracks, and to arrange the tracks so that cars are handled by gravity.

The arrangement of tracks near the top of the slope, and on the surface, is often very similar to the bottom arrangements, as already described; but as all loaded cars (except rock and slate cars, which are run off on a separate switch) are to be sent off on one track, and all the empties come in on the same track to the head of the slope, and as there is usually abundance of room for tracks and sidings, these top arrangements are, in a measure, much more easily designed. In some instances, the two main-slope tracks run into a single track near the head of the slope—a plan somewhat similar to the bottom arrangement shown by Fig. 12—and the cars are then brought to the surface on one track, which, after passing the knuckle, bifurcates into a loaded and empty track. A similar arrangement is frequently adopted at slopes on which a carriage or gunboat is used. When the two main-slope tracks are continued up over the knuckle to the surface—the most common and best plan—the arrangement of tracks and switches may be planned entirely with a view to the quickest and most economical method of handling the cars.

Vertical Curves.—The vertical curves at the knuckle and bottom of a slope or plane should have a sufficiently large radius, so that when passing over them the car will rest on the rail with both front and back wheels. The wheel base of the car must be considered in adopting the radius for these curves, for if the curve is of too short a radius, there is danger of the car jumping the track every time it passes over the curve.

Tracks for Bottom of Shaft.—Fig. 15 shows the arrangement of tracks at the foot of a shaft, with one of the cages at surface. The grades should be so arranged that from the inside latches of the crossings the empty track should have a slight down grade from the shaft, and the loaded track a slight down grade toward the shaft. The crossings and the short straight piece of road close to the shaft should be level.

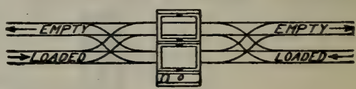


FIG. 15.

As it is often desired to move empty cars from one side of the shaft to the other, without stopping the hoisting, a narrow branch road should be cut through the shaft pillar, and used for this purpose. Where the pitch of the seam prevents this, a road should be laid alongside the shaft, room to accommodate it being cut out of the rock on the side most desirable. (See also Shaft Bottom, page 276.)

In arranging tracks for shaft bottoms, at tops and bottoms of slopes, on coal bins, for mechanical-haulage landings, at foot of slopes or shafts, or in the body of the mine, it is customary to provide double tracks of sufficient length to hold the requisite number of wagons for economically operating the plant and with sufficient distance from center to center of tracks, and from centers of tracks to sides of entries, to easily pass around the wagons where it may be necessary, either in handling them, or in lubricating the wheels. For wagons with a capacity of from 1½ to 2 tons, it generally requires an entry to be about 15 to 17 ft. wide in the clear for ordinary landings in the body of the mine, while at shaft bottoms the necessary width may attain 17 to 18 ft. in the clear, owing largely to location and local requirements. The curved crossovers connecting the tracks at shaft bottoms should be designed with radii of as great length as can be introduced, thereby giving an easy running track. They should not be less than from 20 to 50 ft. on center lines for ordinary gauge of tracks, i. e., 36 to 44 in.

On landings constructed in the body of the mine for the reception of empty and full wagons handled by mechanical haulage from shaft or slope, and from this point transported by animal power to the various working places in the mine, a grade of about 1% in favor of the loaded wagons to be handled by the stock will be found quite an assistance in delivering the wagons to the haulage. The frogs and switches for these landings, as well as those required at the shaft or slope, should be formed of regular track rails, and can generally be arranged to be thrown by a spring or a conveniently located hand lever, as has been described, instead of being kicked to position, as was the custom at one time.

Besides these usual arrangements of shaft-bottom landings, at many plants the natural grades of the entries can be taken advantage of in designing convenient and economical methods for handling the mine cars.

For instance, where the coal is to be hauled from the dip workings of a mine by some form of mechanical haulage, and a summit can conveniently be arranged for in the track on the same side of the hoisting shaft, at the proper distance therefrom, to accommodate the requisite number of loaded wagons to be hauled, thus allowing them to run by gravity over, say, a 1% grade to the shaft, several varieties of empty-track arrangements can be made. The most simple form is to have the empty wagon descend a short grade of from 4% to 5% when pushed from the cage by the succeeding full one. The momentum thus secured is quite sufficient to carry the car up an opposing grade of about 1.5%. It again descends on the same track, and passing through an automatic switch, continues to the empty-car siding. From this latter point it is handled by the regular haulage machinery, and in its route passes around the shaft through an entry especially prepared for this arrangement. A shaft bottom so constructed is very economical to operate, requiring but few men to handle the wagons.

Occasionally, it becomes more expedient to have a separate short haulage to draw the empty wagons to the main haulage when it cannot be easily arranged to construct a complete gravity landing. Several other modifications of such a general design can be made. All the different devices, however, depend largely on the local requirements of the particular mine under consideration.

When endless-rope haulage is employed, it is generally found to be most convenient to have the landings for full and empty wagons, in the body of the mine, reached by switches off of the main-haulage track, the cars coming on and leaving the main track at slight knuckles introduced in the track, in order to allow a place for the passing of the rope, which then moves along through a short cut or channel through the switch rails. The flanges of the wagons pass over the rope in this manner without any injury to it.

Surface Tracks for Slopes and Shafts.—The arrangement of the tracks on the surface naturally differs at every mine, owing to the different existing conditions. All surface roads should be so arranged that the loaded cars can be moved with the least possible power, always looking out for the return of the empties with as little expenditure of power as possible. To secure the running of the loaded cars from the mouth of the shaft or slope by gravity, a slight grade is necessary, the amount of which depends on the friction of the cars, which varies greatly. Care should be take that an excessive grade is not constructed, or there will be trouble in returning the empties from the dump to the head of the shaft or slope.

The tracks connecting the top of the shaft and the tipple may be very short, or of considerable length, depending on the conditions at each mine. Usually from 20 to 60 ft. will be sufficient, although no definite rule can be given for this.

There are two general arrangements of tracks about the head of a shaft: First, where the loaded cars are removed from the cage and the empty cars placed upon it from the same side of the shaft; second, where the loaded cars are removed from one side of the shaft and the empty cars returned to the cages from the opposite side of the shaft.

In either case there are usually several empty cars on the platform ready to be put on the cages when the loaded cars have been removed.

Where the conditions are such that the loaded cars can be run by gravity to the dump, a good plan is to have a short incline, equipped with an endless chain, in the empty track. The empty cars can be run to the foot of this, hoisted by machinery to the top, and thus gain height enough to run them back to the shaft or slope by gravity.

At the Philadelphia & Reading Coal & Iron Co.'s Ellangowan colliery, where the tipple at the head of the breaker is above the level of the head of the shaft, the following plan is used: The loaded cars are taken off the east side of the cages, and run by gravity to the foot of an incline, where the axles of the car are grasped by hooks on an endless chain and the car pulled up to the tipple. After being dumped, the car is run back from the tipple to the head of the incline, and is carried to the foot of the empty track of the incline by an endless chain. The foot of the empty track is several feet higher than that of the loaded track, and the cars are run by gravity around to the west side of the cages, and are put on from that side. The empty cars, as they run on the cage, have momentum enough to start the loaded car off the cage and on toward the foot of the incline. There are a number of hooks attached to both the empty and

loaded chain on the incline, and there are often several loaded and several empty cars on different parts of the plane at once. This arrangement permits of the hoisting of from 700 to 800 cars per day out of a shaft 110 yd. deep, with single-deck cages.

Another excellent arrangement for handling coal on the surface is the invention of Mr. Robert Ramsey, and has been adopted by the H. C. Frick Coke Co. and a number of other prominent operators. A description of this arrangement as applied at the H. C. Frick Coke Co.'s Standard Shaft is as follows: The landing of the shaft is made slightly higher than the level of the tipple, which is north of the shaft. South of the shaft is located a double steam ram, one ram being directly in line with the track on each cage. Directly in front of the rams is a transfer truck, worked east and west by wire rope. The loaded car on the cage is run by gravity to the tipple, where it is dumped by means of a nicely balanced dumping arrangement. As soon as it is empty it rights itself and runs by gravity alongside the shaft to the transfer truck, which carries it up a grade to a point directly in line with the cage that is at the landing, and one of the steam rams pushes it on the cage, and at the same time starts the loaded car off toward the tipple. This second loaded car is then returned by the same means to the opposite cage. The whole mechanism is operated by one man, by means of conveniently arranged levers, each of which is automatically locked, except when the proper time to use it arrives. It is therefore impossible for the topman to work the wrong lever and put an empty car into the wrong compartment of the shaft. Besides the one man at the levers, there is but one other man employed at the tipple, and his work is solely to look after the cars when dumping. All switches are worked automatically, and the average hoisting at this shaft is at the rate of 3 wagons per minute. The shaft is about 250 ft. deep, and single-deck cages are used.

The Lehigh & Wilkes-Barre Coal Co. has a system in use at a number of collieries that has also proven very effective. In this system the loaded cars are run by gravity from the cage to the dump, and the empties are hauled from the dump back to a transfer truck by a system of endless-rope haulage. The transfer truck carries the car to a point opposite the back of the cage. The empty car runs by gravity to the cage, and its momentum starts the loaded car on the cage on its way to the dump. This system necessitates the employment of more topmen, but is a very good one. At the Nottingham shaft, which is 470 ft. from landing to landing, from 140 to 150 cars per hour are hoisted on single-deck cages.

ORE DRESSING AND THE PREPARATION OF COAL.

CRUSHING MACHINERY.

The **object of crushing** ore or coal is: first, to free the mineral or other valuable constituents from the gangue, slate, pyrites (sulphur), or other worthless or objectionable constituents so that they can be subsequently separated; or, second, simply to reduce the size of the individual pieces and so get the material into a more salable or convenient condition for use.

Selection of a Crusher.—The style of crusher employed is influenced by the following conditions: (*a*) The amount of material to be crushed in a given time. (*b*) The size of the material as it goes to the crusher. (*c*) The physical characteristics of the material to be crushed; that is, whether it is hard or soft, tough or brittle, clayey or sticky. (*d*) The object of the crushing; that is, whether it is to free the mineral constituents or simply to reduce the size of the individual pieces. (*e*) The character of the product desired; that is, whether an approximately sized product is desirable and whether dust or fine material is objectionable.

All crushing machinery may be divided into the following classes: Jaw crushers, gyratory crushers, cracking rolls, disintegrating rolls, crushing rolls, roller mills, ball mills, stamp mills, hammers, and miscellaneous forms of crushers.

JAW CRUSHERS.

With jaw crushers, the material is crushed between two jaws, one or both being movable. All jaw crushers have the common defect of imparting a considerable amount of vibration or shake to the framework of the building containing them, owing to the reciprocating motion of the heavy masses that comprise their crushing parts. There are three styles of jaw crushers in common use.

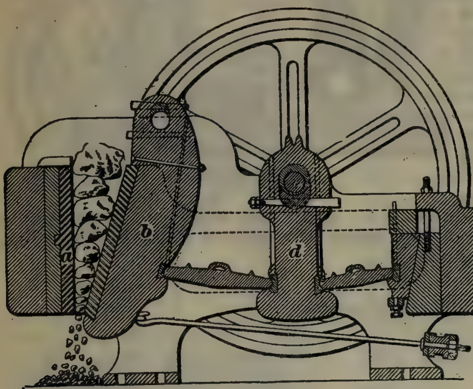


FIG. 1.

The **Blake crusher** is shown in Fig. 1, *a* being a fixed jaw and *b* a movable jaw that is operated by a toggle joint and the pitman *d* from a suitable crankshaft. The jaw *b* is hung or pivoted at the top. The advantages of this style are as follows: The large pieces of rock to be crushed are received between the upper part of the jaws, where the motion is least and the purchase or leverage greatest, so that they are broken with the smallest possible expenditure of energy. The movement of the jaws is greatest at the discharge opening, thus affording a free and rapid discharge of the material crushed, and insuring a large capacity for the machine. The principal disadvantage is that the great variation in the discharge opening results in a considerable range in the size of the material delivered.

This style of crusher has found a wide field for breaking down material and preparing it for other crushers, or for breaking large quantities of any material where an approximate sizing is not essential.

TABLE OF BLAKE CRUSHERS.

Size of Receiving Capacity.	Approximate Product per Hour, Cubic Yards, to 2 Inches.	Weight of Heaviest Piece.	Total Weight.	Extreme Dimensions.						Proper Speed.	Horsepower Required.
				Length.		Breadth.		Height.			
Inches.		Lb.	Lb.	Ft.	In.	Ft.	In.	Ft.	In.		
3 × 1½	Laboratory	40	100	1	1	0	6	0	10	250	½
6 × 2	One	560	1,200	2	10	2	1	2	3	250	4
10 × 4	Three	1,800	4,900	4	0	3	3	3	9	250	6
10 × 7	Five	3,800	8,000	5	1	3	9	4	5	250	8
15 × 9	Eight	7,400	15,500	6	6	5	0	5	11	250	15
15 × 10	Nine	7,800	16,000	6	6	5	5	5	11	250	15
20 × 6	Ten	5,300	11,200	5	3	2	11	4	6	250	15
20 × 10	Ten	8,100	18,300	6	10	5	9	5	11	250	20
12 × 30	Sixteen	14,200	33,000	7	10	8	4	6	4	250	30
15 × 30	Twenty	14,200	35,000	7	10	8	4	6	4	250	30

The **Dodge crusher**, Fig. 2, has a fixed jaw *a* and a movable jaw *b*, operated by a cam on the shaft *g*. The movable jaw is pivoted at the bottom, so that the minimum movement between the jaws is at the discharge opening. The advantage of this is that the least movement occurs at the discharge opening,

and hence the product is of a fairly uniform size, so that the crusher may be used as a rough sizing apparatus. The disadvantages are that the large pieces of rock have to be crushed in the upper part of the space between the jaws, where the motion is greatest and the purchase or leverage least, thus requiring an excessive amount of power, especially when dealing with hard material. The movement of the jaw at the discharge opening is so much less than that above that there is danger of clogging or blocking the machine, especially when working upon tough or sticky material. The capacity of the Dodge style of machine is less than that of the Blake. It is used largely as a secondary crusher, or for crushing comparatively small amounts of material where an approximately sized product is desired.

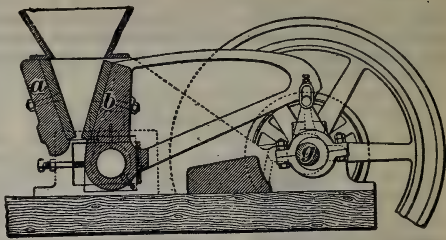


FIG. 2.

THE DODGE CRUSHER.

No.	Size of Jaw Opening.	Diameter of Pulleys.	Width of Belt Used.	Horsepower Required.	No. Tons per Hour, Nut Size.	Revolutions per Minute.	Weight Complete.
	Inches.	Inches.	Inches.				
1	4 × 6	20	4	2 to 4	½ to 1	275	1,200
2	7 × 9	24	5	4 to 8	1 to 3	235	4,300
3	8 × 12	30	6	8 to 12	2 to 5	220	5,600
4	10 × 16	36	8	12 to 18	5 to 8	200	12,000

Roll-Jaw Crushers.—Fig. 3 is a sectional view of a Sturtevant roll-jaw crusher. The rolling motion of the jaw subjects the material to a rolling and squeezing action, instead of a direct squeeze. The product of this crusher is approximately sized and there is no greater producer of sized output. The adjustment of the machine for fine crushing necessarily contracts the space for discharge, and thereby lessens its capacity. When set wide, or for material from 1 to 1½ inches in size, the discharge is very free and the capacity is claimed to be greater than that of any other jaw and toggle machine.

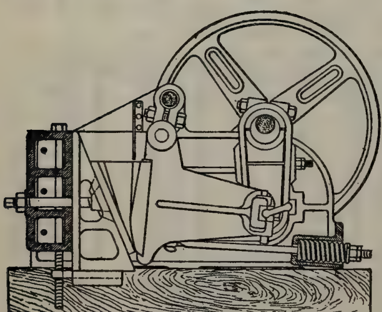


FIG. 3.

Gyratory Crushers.—These crushers, Fig. 4, are all large capacity, continuous-action crushers. *a* is a ring or hopper against which the material is crushed by a conical head *c*, which fits on a shaft *g*, the bottom of which is placed in an eccentric bearing so that the amount of space between *a* and *c* varies as the head rotates. The material to be crushed is dumped into the receiving hopper *h*, and the machine is thus automatically fed.

The advantages of this style are that the large pieces of material are received at the top of the jaws, where the motion is least and the leverage or purchase greatest, thus reducing the work necessary in this heavy preliminary crushing. The relative movement between the crushing members is a maximum at the discharge opening, but the amount of this movement is so small that the product is approximately sized. The fact that the maximum movement is at the point of discharge assures a free discharge. There is practically no shaking imparted to the building by gyratory crushers. Their capacity is very great, and with a large size, material may be dumped into the hopper *h* directly from the cars. For small capacity a gyratory crusher is more expensive than a jaw crusher.

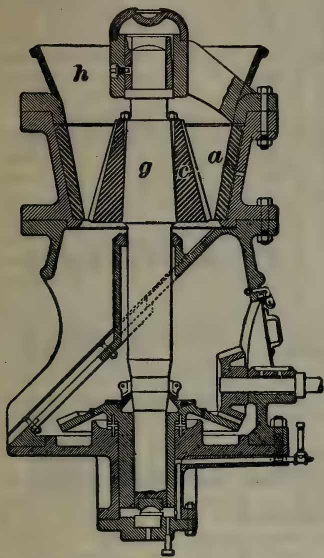


FIG. 4.

Frequently, where very great amounts of material are to be crushed, large gyratory crushers are used as secondary crushers after jaw crushers of the Blake pattern, the discharge from the jaw crushers ranging from 6″ to 12″ cubes, and that from the gyratory crushers from 1½″ to 2½″ cubes. (See table on page 422).

ROLLS.

Cracking Rolls.—This is a general name applied to rolls having teeth, which are usually made separate and inserted. These rolls, Fig. 5, are employed for breaking coal, phosphate rock, etc., the object being to break the material into angular pieces with the smallest possible production of very fine material. The principal field for cracking rolls is in the preparation of anthracite coal, and the exact style or design of the roll depends largely on the physical condition of the coal under treatment. In most cases, the rolls are constructed with an iron cylinder having steel teeth inserted, the size, spacing, and form of the teeth depending on the size and physical condition of the material to be broken. Cracking rolls vary from 12 to 48 in. in diameter and from 24 to 36 in. in face width. The teeth of the larger sizes are from 3 to 3½ in. high, and of the smaller 1 in. or less.

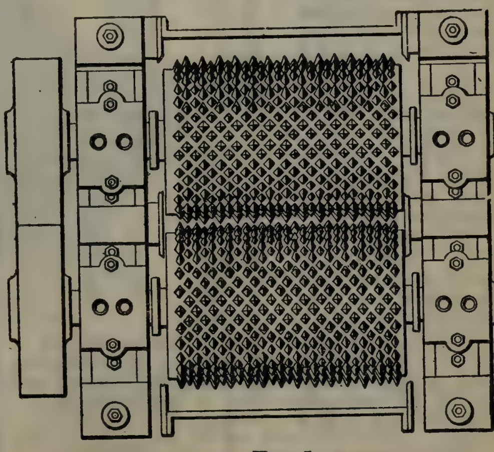


FIG. 5.

The average practice in the anthracite regions of Pennsylvania is to give the points of the teeth a speed of about 1,000 ft. per minute, though the speed in different cases varies from 750 to 1,200 ft. per minute. One of the largest anthracite companies has a standard roll speed of 97.5 R. P. M. for the main rolls and 124.5 R. P. M. for the pony rolls. The harder the coal, the faster the rolls can be run. If run slow and overcrowded, the rolls will make more culm than when driven at a proper speed. One advantage of comparatively fast driven rolls is that the higher speed has a tendency to free the rolls by throwing out, by centrifugal force, any material lodged between the

teeth. In one test it was found that less fine coal was produced at 800 ft. per minute, but that the rolls blocked at this speed and hence had to be driven 1,000 ft. per minute.

In one case a pair of main rolls 24 in. in diameter, 36 in. face, running at 1,000 ft. per minute, handled 2,500 tons of coal in 24 hours. A pair of 19″ × 24″ main rolls run at 1,000 ft. per minute handled 300 tons mine run in 10 hours.

A well-known maker of rolls for crushing bituminous coal gives a speed of 100 to 150 R. P. M., according to the output required, for rolls 24 in. in diameter and 33 in. long. As a rule, cracking rolls are never run up to their full capacity, as is the case with crushing rolls.

The *form of the teeth* varies greatly, but, as a rule, the larger rolls have straight pointed teeth of the sparrow-bill or some similar form, Fig. 6 *a*. The old curved, or hawk-billed, teeth, Fig. 6 *b*, have now gone almost wholly out of use.

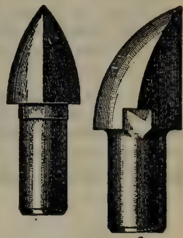
On small sized rolls, rectangular teeth with a height equal to one side of the square base are frequently employed, and these may be cast in segments of manganese or chrome steel.

Corrugated rolls have teeth or corrugations extending their entire length. They were first introduced by

DIMENSIONS, WEIGHTS, CAPACITIES, AND REQUIRED POWER OF THE GATES ROTARY CRUSHER.

Size.	Dimensions of Each Receiving Opening, About	Dimensions of Three Receiving Openings Combined, About	Weight of Breaker.	Capacity per Hour, in Tons of 2,000 Lb., Passing 2¼ In. Ring, According to Character of Rock or Ore.	Dimensions of Driving Pulley.		Revolutions of Driving Pulley.	Space Occupied by Breaker.			Diameter of Hopper.	Size Engine Recommended to Drive Breaker, Elevator, and Screen.	
					Inches.			Inches.				Indicated Horsepower.	
	Inches.	Inches.	Pounds.		Diam.	Face.		Height From Bottom Frame to Top Hopper.	Width of Frame.	Length of Frame.	Inches.	Limestone.	Granite, Ore.
00	2 × 4	2 × 12	500		8	2⅝	700	24	17	26	13	1	1
0	4 × 10	4 × 30	3,300	2 to 4	16	6	500	50	30	73	28	4	4
1	5 × 12	5 × 36	5,600	4 to 8	20	7	475	55	31	76	42¼	8	8
2	6 × 14	6 × 42	7,800	6 to 12	24	8	450	61	39	90	46¼	12	15
3	7 × 15	7 × 45	13,800	10 to 20	28	10	425	75	48	103	54⅛	20	30
4	8 × 18	8 × 54	21,500	15 to 30	32	12	400	91	54	114	79¾	30	40
5	10 × 20	10 × 60	30,000	25 to 40	36	14	375	101	63	123	88	40	50
6	11 × 24	11 × 72	40,500	30 to 60	40	16	350	114	73	139	103	50	60
7½	14 × 30	14 × 90	65,800	50 to 125	44	18	350	144	84	145	120	80	125
8	18 × 42	18 × 126	89,000	100 to 150	48	20	350	156	90	164	132	125	150

Mr. E. B. Coxe, at Drifton, Pa., but they have not come into general use owing to the fact that, while they break some coal fairly well, in most cases it has been found that a continuous edge causes too much disintegration along its length, while a point splits the coal into three or four pieces only, all the cracks radiating from the place where the point strikes, thus producing very much less culm. Another advantage possessed by the toothed rolls is that if anything hard passes through the corrugated roll and breaks out a piece of the corrugation, the entire roll is ruined, while, in the case of the toothed rolls, any one of the teeth may be replaced.



a *b*

FIG. 6.

Disintegrating rolls and pulverizers are sometimes used to reduce coking coal to the size of corn or rice before introducing it into the ovens. One roll is driven at double the speed of the other, the slower roll acting as a feed-roll, and the other as a disintegrator. The slower roll is commonly driven at from 1,800 to 2,000 ft. per minute peripheral speed, and the faster roll at from 3,600 to 4,000 ft. per minute. The teeth are always fine, rarely being over $\frac{3}{8}$ in. high. In some cases, the inner roll is provided with a series of saw teeth from $\frac{1}{4}$ in. to $\frac{3}{8}$ in. high and having about $\frac{3}{8}$ in. pitch, the individual teeth being set so as to form a slight spiral about the body of the roll. The other roll is provided with teeth having their greatest dimension in the direction of rotation, so that they tend to cross the teeth on the opposite roll. These teeth are also set so as to form a slight spiral, and thus prevent blocking. In other cases, the teeth on both rolls are set in the form of quite a steep spiral.

Hammers.—For the reduction of coal, crushers employing hammers have been used, Fig. 7. The crushing chamber is usually of a circular or barrel form, and the crushing is done by means of hammers pivoted about a central shaft. These swing out by centrifugal force and strike blows upon the coal to be broken. When it is reduced sufficiently fine, it is discharged through bars or gratings at the lower portion of the machine. This style of machinery is usually employed in preparing coal for coke ovens, thus occupying the same field as the disintegrating rolls. A No. 3 pulverizer of this type will crush 50 to 75 tons per hour run of mine, down to $\frac{1}{8}$ in., or it will crush 100 tons per hour of slack. Such a machine occupies about 8 sq. ft. of floor space and requires 25 to 30 H. P. to run it.

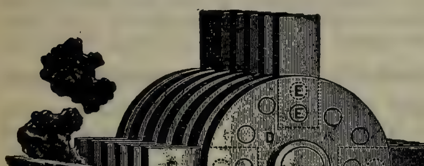


FIG. 7.

Crushing Rolls.—The principal representative of this type of machine is the ordinary Cornish roll having a fairly wide face and rather small diameter. The diameter of these rolls was kept down for a great many years on account of the fact that the chilled cast-iron shells could not be obtained in large sizes and were expensive and hard to handle. With the advent of the rolled-steel shells, it became possible to employ larger diameters and higher speeds. Rolls of the Cornish type vary from 4″ face and 9″ diameter to 16″ face and 42″ diameter. The distinctive feature of the Cornish roll is a comparatively wide face compared with the diameter, and a rather slow peripheral speed. Many of the modern Cornish rolls are provided with rolled-steel shells, especially when employed for very fine crushing, owing to the fact that these shells are of a more uniform texture, work more evenly, can be worn much thinner before being discarded, and can be trued up with less difficulty than is the case when chilled iron is employed. To guard against the bending of the roll

shaft or breaking of the machine in case any hard material (such as a pick or hammer) gets between the rolls, one roll is mounted in a movable bearing and kept in place by a compressed spring washer. This washer is composed of two plates between which are placed one or more steel springs. The plates are kept together by several small bolts, which are screwed up so as to compress the springs to a certain degree. Then the entire arrangement is employed as a washer on the rod that keeps the rolls together. Should the pressure exerted on the rolls exceed that already exerted in the spring, the plates would be brought nearer together and the roll allowed to move back and pass the hard substance, but at any pressure below this, the roll acts as if placed in a fixed bearing.

Cracking, corrugated, and disintegrating rolls are usually provided with breaking pieces back of one of the rolls, so that in case any extra hard piece passes through the rolls, the breaking piece will give way, allowing the rolls to move back and thus prevent the bending of the shaft or breaking of the machine itself. Compressed spring washers have never come into general use in connection with this style of machinery.

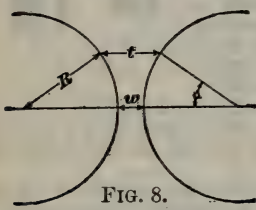


FIG. 8.

Amount Crushed.—The amount of material that can pass between any pair of rolls is proportionate to the number of square feet of roll surface passing per minute; hence, the capacity may be increased by keeping the face width the same and increasing the speed, or the same capacity may be obtained by reducing the face and increasing the speed.

According to Stutz (A. I. M. E. IX, page 464), if the distance between the contact points of the material with the rolls be t, Fig. 8, the distance between the crushing face of the rolls w, the angle α, as shown in the figure, and R the radius of the roll, then

$$R = \frac{t-w}{2 \text{ vers. } \sin \alpha} = \frac{t-w}{2(1-\cos \alpha)}.$$

According to Pernolet, the amount of material that may be crushed by a pair of rolls in a given time is equal to one-fourth or one-fifth of a band or layer whose length is the circumference of the roll multiplied by the number of revolutions; whose width is the length of the rolls, and whose thickness is equal to the space or distance between the rolls. Or, $Q = \frac{d\pi n l w}{4}$, where d = diameter of rolls; $\pi = 3.14$; n = number of revolutions in the given time; l = length of rolls; w = space between rolls; and $\frac{1}{4}$ = coefficient, to allow for the irregular feeding of the material and the space between the pieces.

The Denver Engineering Works gives the following formulas for the capacity of crushing rolls:

T = tons per hour; R = rev. per min.; S = mesh (inches).

For 14″ × 27″ rolls, $T = 7.725\, R\, S$.
For 16″ × 36″ rolls, $T = 11.775\, R\, S$.
For 12″ × 20″ rolls, $T = 4.9\, R\, S$.

Speeds.—The pressure on the bearings necessary to crush ore depends directly on the face width, and hence if the capacity can be kept the same and the face width decreased, it is evident that there will be less pressure on the bearings and less loss in friction. The difficulty of keeping the bearings cool when crushing hard rock with the old Cornish rolls has led to the adoption of high-speed, narrow-faced rolls for certain classes of work. One objection to running the small diameter rolls fast is that the larger pieces of ore have a tendency to dance on the face of the rolls rather than to be crushed, while the bite is better when the speed is slower.

The advantages of high-speed, narrow-faced rolls are: greater capacity for a given bearing pressure; less loss of power from friction; less dancing of the ore on the roll face, owing to the fact that the angle of approach between the surfaces of large rolls is more acute than with rolls of a small diameter. High-speed, large-diameter rolls will handle coarser material and hence make a greater range of reduction than small-diameter rolls. The disadvantage of high-speed rolls is that they tend to hammer and pulverize the ore, so that with very brittle minerals a high speed may be detrimental. In general, it may be stated that for crushing to any definite size with the lowest possible production of very fine material, rolls are the best form of

machinery on the market. For fine crushing of brittle material, quite slow speeds may give the best results.

The accompanying table gives some facts in regard to the crushing-roll practice of several manufacturers, the data having been taken from their catalogues or other information furnished by them.

CRUSHING ROLLS.

Name.	Size. Inches.	Peripheral Speed in Ft. per Min.	Spring Pressure in Lb. per In. of Face Width.	Character of Rolls.
Frazer & Chalmers...	24 × 8 36 × 16	600–1,500	4,000 for hard quartz.	Cornish.
Frazer & Chalmers...	44 × 5 56 × 8	2,200–2,300		Narrow face, high speed.
Earle C. Bacon..........		1,000		Cornish.
Sturtevant Mill Co.	16 × 3 27 × 5	3,000		Special centrifugal.
E. P. Allis Co.	20 × 12 26 × 14 30 × 14 36 × 14	800		Cornish.
E. P. Allis Co.		1,885		Narrow face, high speed.
Colorado Iron Works	20 × 12 27 × 14 36 × 16 40 × 16	600	4,000 for hard rock. 4,800 for very hard rock.	Cornish.
Colorado Iron Works	36 × 6 42 × 6 54 × 8	2,100–2,800		Narrow face, high speed.
Denver Engineering Works Co.	20 × 12 to 36 × 16	350–100	3,500–4,500	Cornish.
Gates Iron Works	9 × 4 26 × 15 36 × 15	470–850	2,266–3,333	Cornish.

The Gates Iron Works has furnished the following formulas relating to crushing rolls, in which D = diameter of roll in inches; N = number of R. P. M.; S = maximum size of ore cube in inches fed to the rolls; S' = maximum size of cube for a given diameter of roll.

$$N = \frac{382}{D} \times \frac{\log \frac{16}{S}}{\log 2}. \quad S' = 0476 \times D.$$

It will be seen from the first of these formulas than N is an inverse function of S, which agrees with the results shown in the previous diagram. As a rule, it is best not to try to run rolls up to the maximum size that they will crush, but to feed smaller material to them.

The Denver Engineering Works Company has furnished the diagram, Fig. 9, and formulas relating to rolls. This diagram serves very well to illustrate the fact that small rolls do not grip or crush large pieces as well when running at comparatively high peripheral speeds as when running at slow speeds. In the case of the 10″ × 16″ roll, a difference of from 1″ to ½″ cube size made a difference of 20 R. P. M. in order to obtain the

most effective crushing speed, and the difference between $\frac{1}{2}''$ and $\frac{1}{4}''$ cube sizes made a difference almost as great. It will also be noticed that the larger diameters, as, for instance, the 42″ roll, are not so greatly affected by this cause, owing to the fact that the effective or crushing angle between the rolls is much more acute than in the case of the smaller diameters.

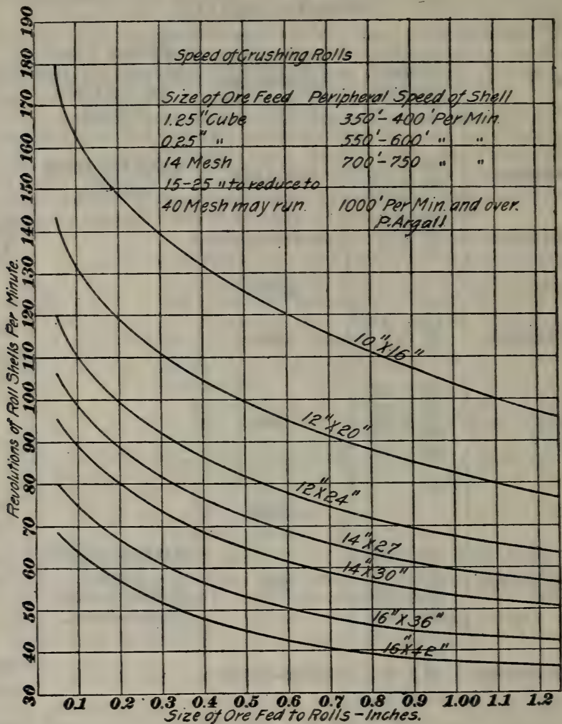


FIG. 9.

CRUSHING MILLS.

Radial Roller Mills.—In this type of mill, the crushing is performed on a ring or die by a series of heavy rolls pressing on it by gravity. In some cases, the rolls travel around on the die and in others the die travels in relation to the rolls. Fig. 10 represents one form of Chilian mill that is the leading type of this class.

The peculiarity of the grinding action of the radial rolling mills is that it is not a pure crushing action, but a triturating or grinding action as well, owing to the fact that while the different portions of the face of the roll are all traveling at the same speed, the outer portions have to travel over a greater length of ring than the inner portions, so that there is only one line along which true crushing action occurs. Some manufacturers have made the crushing ring and the rollers both with coning faces, the vertices of both cones meeting at a common point. This has resulted in a true crushing action, but for some classes of work the triturating action is to be preferred, as, for instance, in the grinding of silver ores for the patio process of amalgamation.

Centrifugal Roller Mills.—In centrifugal roller mills, the crushing is accomplished between rapidly moving rolls and the inside of a stationary die or ring. The Huntington mill, Fig. 11, is one of the principal representatives of this class of machinery. The rollers *c* are supported from bearings *e* and are carried rapidly around by means of the frame *a* and the shaft *g*. The ore is crushed against the ring *d*. In order to prevent the accumulation

of ore below the rollers, and to throw it out for crushing, scrapers *f* are provided. The crushed ore discharges through screens, as shown in the illustration. There are many styles of this class of machinery having different numbers of rollers, varying from 1 up, and some machines have been introduced combining a portion of the action of radial and centrifugal machines, the faces of the die or ring being at an angle and the rollers being mounted in inclined bearings so that they tend to crowd out and down upon the ring. Centrifugal roller mills have found two especial fields in concentration works, one for crushing clay or soft ores containing free gold, and the other for regrinding middlings for further concentration. Rolls of this type are also extensively employed in grinding cement and phosphate rocks.

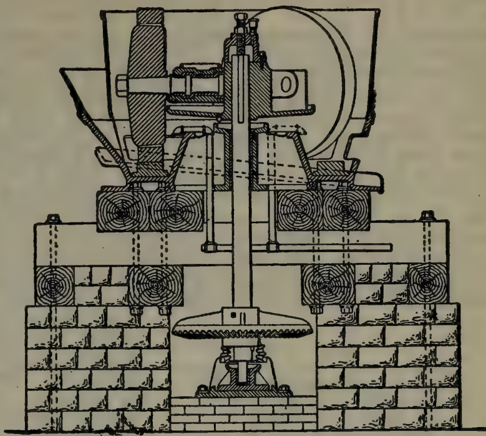


FIG. 10.

Ball Mills.—There are two types of ball mills: (1) those in which the crushing is performed by balls traveling in a fixed path, and (2) those in which the crushing is performed by a large mass of balls of various sizes rolling over one another. In the first type the balls travel in a fixed path, track, or race that may be either vertical or horizontal. Where it is vertical, the balls must be driven at such a rapid rate that their centrifugal force will keep them in contact with the crushing ring or track. This form may be likened to a bicycle ball bearing on a large scale, the crushing being accomplished between the balls and the race or track. The serious objection to this class of ball mills is found in the uneven wear of both the balls and the race, so that the work soon becomes unevenly distributed, and also in the fact that the balls cannot be used after they have been worn to a slight extent.

In the second class of machines the balls are introduced into a large barrel or chamber, where they roll over one another, the ore being crushed between the different balls and between the balls and the lining of the chamber. In this style of machine the crushed material may be discharged through openings in the periphery or through openings in one end of the barrel. One great advantage with this style of mill is that the balls can be entirely worn out and it is only necessary to charge a sufficient number of new balls with the ore each day to make up for the wear of those in the mill.

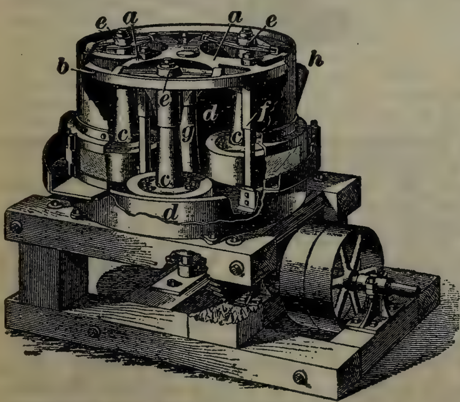


FIG. 11.

STAMPS.

Gravity stamps are especially well suited for material the valuable portion of which does not have a tendency to slime. The fact that these stamps are very simple in construction, easy to transport and erect, as well as to operate, gives them a decided advantage over other forms of crushers. Fig. 12 illustrates a 10-stamp battery of the gravity type.

Fig. 13 is a detail of the mortar stamp heads and dies. The mortar *a* is placed on a suitable foundation of timbers *b* and the ore crushed on dies *d* by the stamps *s*, which are secured by means of tapered joints to the heads or bosses *h*. The stems *e* are attached to the heads *h* and the whole lifted by the cams (shown in detail in Fig. 12). The cams operate under tappets on the stems, as shown in Fig. 12. As the cam operates under the edge of the tappet, it not only lifts the stamp, but gives a partial rotation, thus equalizing the wear on both the stamp and die. The ore is fed in at the back of the mortar and the crushed material discharged through the screen, as shown in Figs. 12 and 13. Usually a single screen at the front is employed, but sometimes two or more upon different sides of the mortar may be introduced. For treating free-milling gold ores in which the gold occurs in rather large grains free from iron pyrites, the *California* style of battery was developed, the characteristics of which are a small drop (4 in. to 6 in.), low discharge (4 in.), a heavy stamp (750 to 1,000 lb.), and a high speed or number of drops per minute (90 to 105). The advantage of this style is rapid crushing, but the majority of the gold had to be saved on apron plates outside the mortar.

For working ores that contain large quantities of iron pyrites with the gold values occurring in the cleavage planes of the pyrites, the *Gilpin County*, Colo., style of battery was developed. This is characterized by a high drop (18 to 20 in.), a high discharge (14 in.), a light stamp (550 to 600 lb.), and a comparatively slow rate of drop (30 per minute). With this style of battery, most of the gold was obtained on amalgamated plates in the battery, but its use was accompanied by excessive sliming on account of the fact that the high discharge kept the material in the mortar for a long time, and subjected it to repeated treatment.

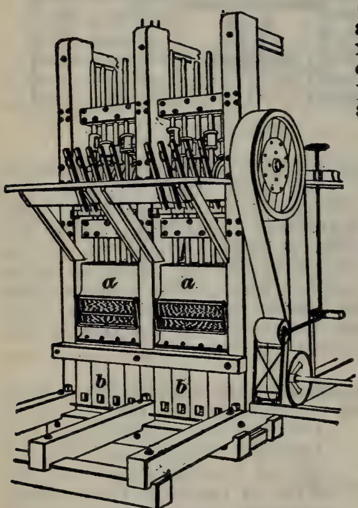


FIG. 12.

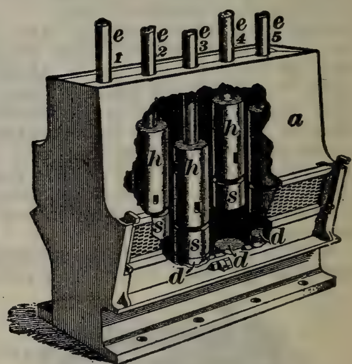


FIG. 13.

Modern practice tends toward the use of rather heavy stamps (about 1,000 lb.), quick drop (90 to 105 per minute), and low discharge (4 to 6 in.). The advantages are that the capacity of the battery is very great and the sliming reduced to a minimum. If the ore contains sulphides carrying gold, they are separated by concentration upon vanners or bumping tables, and subsequently treated by chlorination or smelting. If the apron plates do not catch the major portion of the values, the tailings may be treated by the cyanide process. This last method is that employed at many large gold mines, especially those of the Transvaal in South Africa.

Order of Drop.—There is much diversity of practice in this respect. It is desirable to drop the stamps in such rotation as to insure an even distribution of the pulp on the several dies. Adjacent stamps should not drop consecutively, as this occasions accumulation of the pulp at one end of the mortar, in consequence of which the efficiency of the stamps at that end is reduced by having a decreased height of drop and a cushion that retards the pulverization of the ore. The stamps at the other end of the mortar have too little work, and are liable to "pound iron." The order of drop 1, 4, 2, 5, 3

seems to best fulfil the requirements. It gives a good splash and satisfactory results in other respects. The order 1, 5, 2, 4, 3 is also extensively adopted. There are several other orders of drops in use, but the two just mentioned are generally preferred.

In large mills, the standard drop is given as 1, 7, 3, 9, 5, 2, 8, 4, 10, 6, with 1, 8, 4, 10, 2, 7, 5, 9, 3, 6 as a close favorite; while 1, 5, 9, 7, 3, 2, 6, 10, 8, 4 and 1, 5, 9, 3, 7, 10, 6, 2, 8, 4 are used.

Speed of Stamps.—Heavy stamps and stamps having high drops should have correspondingly low speed. With 900- to 950-lb. stamps, having 6″ to 7″ drop, the speed should be from 85 to 95 drops per minute. With double-armed cams, the speed must not be great enough to bring the cam into collision with the falling tappet, i. e., the interval between the revolutions of the cam must be sufficient to give the tappet time to finish its drop. When the cam strikes the descending tappet, a shoe, boss, or tappet is often dislodged, and breakage is imminent. A fast drop produces a good splash, which is very desirable for battery amalgamation.

Shoes and Dies.—Shoes and dies are either of iron or steel. In most mills, remote from foundries where transportation is an important item in the cost of shoes and dies, steel shoes and dies have replaced those of iron. Chrome steel shoes and dies have been introduced and have proved superior. In some mills, steel shoes and iron dies are used. The iron dies wear more evenly with steel shoes than the steel dies do. The life is about 2½ to 3 times that of iron shoes and dies, and the cost about twice as great as those of iron. The mixture of steel (from the old chrome steel shoes and dies) with iron produces shoes and dies that wear considerably longer than those of pure iron, and may be advantageously introduced where there is no other disposition possible for the old steel, because of want of local facilities for the utilization of this residue. In many districts, the old iron shoes and dies are sold to local foundries for from 1½ to 2 cents per lb.

The weights of the shoes bear a certain relation to the weights of the tappets, stems, and bosses. Chrome steel shoes made for stamps of 850 to 950 lb., weigh from 150 to 155 lb., and measure about 9 in. in diameter by 7½ to 8 in. long. The neck is from 4½ to 5 in. long, with a taper to correspond to the socket of the boss or stamp head. Iron shoes are usually from 15 to 20 lb. lighter than the above weights. The chrome steel dies weigh from 110 to 125 lb., and measure (where shoes of the above dimensions are used) 9 in. in diameter by 4 to 4½ in. in height, with a rectangular foot-plate 10¼ in. by 9¼ in. by ½ in. thick. Iron shoes usually weigh from 20 to 25 lb. less than the above weights for steel.

Life of the Shoes and Dies.—There are many conditions that affect the durability of shoes and dies, as, for instance, the hardness of the rock, the weight, speed, and height of drop of the stamp, the manner of feeding the ore, etc. Iron shoes of good quality last from 30 to 47 days. Old shoes wear usually down to 1½ in. or 1 in. in thickness, and weigh about 25 or 40 lb. Old dies usually wear down to about 1½ in. in thickness, and weigh from 20 to 50 lb. The consumption of iron or steel in shoes and dies depends on the character of the ore crushed. Other conditions being the same, it will depend on the coarseness of the stamping and the height of discharge. Dies wear less rapidly than the shoes, as they are protected by the thickness and the pulp, which covers them to the depth of from 1½ to 3 in. But while the actual wear of dies is less than that of the shoes, the life of the dies is shorter than that of the shoes, owing to the fact that the shoes have several inches greater length of wearing part than the dies. The consumption of iron for shoes and dies per ton of ore crushed is, in California, from 1½ to 3 lb. To obtain the maximum crushing capacity of the battery, the dies must be kept as high (with reference to the lower edge of the screens) as is compatible with the safety of the screens and with successful amalgamation in the battery. To prevent the pounding of iron, it is necessary to preserve more or less uniformity in the level of the dies. Should one die in the battery project much above the others, little or no pulp would remain upon it, and the shoe would consequently drop upon the naked die.

Cams, Stamp Heads, and Stems.—Cams and stamp heads ought to last several years. They are usually broken through carelessness. The stems break at the socket of the stamp head. Stems are reversible; when broken, they may be swedged or planed down and additional lengths welded on when necessary.

Tappets.—When there is much grease on the tappet or cam or when the

tappets have so worn that the face of the cam strikes a grooved instead of a level face on a tappet, the rotary motion is greatly impaired. Tappets last for several years, from 4 to 5 years being their usual life. Sometimes they are broken by being too tightly keyed. When their faces are worn, they are planed down. They are reversible, so that when one face has been worn as far as possible, the other face is placed downwards. They are usually of steel, and weigh about 112 lb. when 900-lb. stamps are used.

Battery Water.—The amount of water fed to the battery depends on the character of the ore and the size of the screen. Clayey and highly sulphureted ores require the maximum amount of water. The amount of water used per ton of ore stamped varies from 1,000 to 2,400 gallons. The mean amount used per ton of ore stamped is about 1,800 gallons. From $\frac{3}{4}$ to $1\frac{1}{2}$ miner's inches per battery should be provided. In winter, when the battery water is chilly, it should, when possible, be heated to tepidity, as this promotes amalgamation. A high temperature should be avoided, as it renders the quicksilver too lively.

Duty of Stamps.—The capacity of gravity stamps varies from a little over 1 ton per stamp for 24 hours to as high as 4 tons per stamp for 24 hours, depending on the quality of the ore. Usually, an average of from 1.7 to 2 tons per stamp for 24 hours in a combination mill would be good practice, while where the ore is crushed to a rather coarse screen and the tailings treated with the cyanide process, a larger capacity is usually obtained.

The number of tons of ore crushed per stamp depends chiefly on the weight of the stamp, the number of drops per minute, the height of drop, the height of discharge, the size of the screens, the width of the mortar, and chiefly on the character of the ore. Hard ores and ores of a clayey nature (from the difficulty experienced in discharging the clayey pulp) decrease the duty of the stamps. About $2\frac{1}{4}$ tons per stamp in 24 hours is the average duty of the stamp in California. The discharging capacity of a mortar depends on the height and size of the discharge opening, the character of the screen, and the width of the mortar discharge, as will be illustrated from two well-known mills.

The Homestake Mill uses an 850-lb. stamp dropped 9 in., 85 times per minute, developing 78,030,000 ft.-lb. in 24 hours, and crushing $4\frac{1}{2}$ tons of rock, or 1 ton for every 17,340,000 ft.-lb. developed.

The Caledonia Mill uses an 850-lb. stamp, dropping 12 in., 74 times per minute, crushing 3.3 tons, of rock and developing 90,576,000 ft.-lb. in 24 hours, or 1 ton to every 24,447,272 ft.-lb. developed. Although developing more foot-pounds in 24 hours, and therefore seemingly more efficient, yet it crushes less rock than the former. The reasons for this are (1) that the rock is harder than that of the Homestake; (2) the width of mortar is 16 in. against $13\frac{1}{2}$ in.; and (3) the 2″ recess for the 8″ copper plate below the feed. On the other hand, the Caledonia has a lower discharge from the mortar, using 6 in. against 10 in. in the Homestake; but this advantage is again neutralized by a smaller screen, the Caledonia using 258 sq. in. against 376 sq. in. of the Homestake.

Horsepower of Stamps.—The H. P. of a stamp battery =

$$\frac{\text{No. of stamps} \times \text{wgt. of each stamp} \times \text{No. of drops per min.} \times \text{drop of each in in.}}{12 \times 33{,}000}$$

The weight of each stamp is equal to the sum of the weights of the stem, tappet, stamp head, and shoe. To the nominal H. P. add 25% for friction of machinery in calculating driving H. P.

Cost of Stamping.—The cost of stamping varies from a little over $1.00 per ton up. The Montana Co., Limited, operating a 60-stamp combination mill, in 1888 treated 40,530 tons of ore at $1.13 per ton. In Australia, stamp-mill costs have been reported varying from $1.30 to $2.50 per ton where fairly favorable conditions for working could be obtained. Figures from other districts compare favorably with these, but it would be impossible to give any absolute rule by means of which the cost can be determined in advance, without an intimate knowledge of the character of the ore and the local conditions.

Pneumatic Stamps.—This is a name given to a form of large capacity power stamp, the head of which is connected to a piston in an air cylinder. The cylinder is raised and lowered by power, the air forming an elastic connection by means of which the stamp is operated. They are quite extensively employed in crushing tin ore, but have never come into general use for other purposes. The capacity is as high as 30 tons per 24 hours.

Power Stamps.—Various forms of stamps have been brought out at different times, intended to operate by power like a trip hammer, or in which the stamps were connected directly to the cranks operating them by means of spring joints. Nearly all of these forms have failed on account of excessive wear, small capacity, and the large amount of power consumed.

Steam Stamps.—The large capacity steam stamp, which was evolved in connection with the concentration of the Lake Superior copper ores, consists of a steam cylinder in which operates a piston, to the stem of which the stamp head is directly connected. Machines of this style are usually made very large and heavy, frequently extending through two or three stories of the mill, and having a capacity equivalent to from 60 to 100 ordinary gravity stamps. In most forms, live steam is admitted on top of the piston during the descent of the stamp, thus increasing the force of the blow. For lifting the stamp, the steam is throttled so that a lower pressure is employed. The discharge is usually through a coarse screen, $\frac{3}{8}''$ to $\frac{5}{8}''$ mesh not being uncommon. One interesting fact connected with the large steam stamps is that their heavy blows do not cause as excessive sliming as the lighter gravity stamps, and on this account this form of stamp has been introduced in some cases for crushing free-milling gold ores.

For prospecting work, for testing properties, or for operating small properties, a number of forms of portable or semiportable steam stamps have come out during the last few years. One of these (the Tremain) is illustrated in Fig. 14. In this form, two pistons work in cylinders side by side and strike alternate blows in a common mortar. The steam is introduced at full boiler pressure on the lower side of the cylinder, which, owing to the large diameter of the piston rod, has a small area. This high pressure steam is then allowed to expand on to the top of the piston, thus urging it down with greater force than its own weight would. These steam stamps can be run at a much higher speed than gravity stamps, and hence have a greater capacity. In the figure shown, three screens are employed, one in front and one at each end of the mortar. There are several other forms of portable steam stamps manufactured. They all have the advantage that for a small property they can be installed with much less trouble than any other form of crusher, owing to the fact that no steam engine is required and the steam necessary to drive them can usually be obtained from the boiler operating the hoisting engine, pumps, etc.

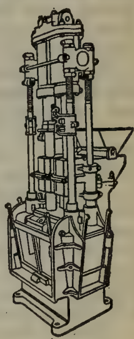


FIG. 14.

Miscellaneous Forms of Crushers.—Most crushers can be classed under one of the previous heads, but there are some forms that depend on the material itself to do the crushing. For instance, in the preparation of coal for coke ovens, there has been a combined crusher and separator invented that may be described as follows: A large horizontal drum or cylinder, provided with screen openings around its periphery, is mounted in a horizontal position. The coal to be separated is fed into one end and is caught by shelves or plates projecting radially into the cylinder. These lift the material to the upper side, from which it falls by gravity and strikes the bottom, thus crushing the softer parts. The sulphur and slate, being harder than the coal, are not crushed by the same height of fall, and hence, by a proper adjustment of the diameter of the cylinder, the coal may be crushed and discharged through the screen while the slate and sulphur will pass out at the opposite end of the cylinder.

SIZING AND CLASSIFYING APPARATUS.

Stationary Screens, Grizzlies, Head-Bars, or Platform Bars.—These are the various names given to an inclined screen employed for removing the fine material from the run of mine so that only the coarse portion will be passed to the crushers. At concentrating works, the term *grizzly* is usually employed, and a common form is shown in Fig. 15. This is composed of flat bars held apart by cast-iron washers through which the bar bolts are passed to hold the entire frame together. Grizzlies are usually placed at an angle of from 45° to 55°, and ordinarily, for the head of a large concentrating works, they are from 3 to 6 ft. wide and from 8 to 12 ft. long, the amount of space between the bars depending on the size of the run-of-mine material and on its subsequent treatment.

In the anthracite coal breakers, the terms *platform bars* or *head-bars* are usually employed, and these bars are made of $1\frac{1}{2}''$ to $2''$ round iron placed at an inclination of 5 in. to 1 ft., the spacing depending on the size of coal it is desired to make in the breaker.

At the present time, in accordance with an agreement between the operators and the miners' officials, the standard size for a bituminous lump screen (the bars are called a screen) for Ohio, Pennsylvania, Indiana, and Illinois is 12 ft. long and 6 ft. wide over the screen surface. The screen consists of 6 bearing bars 4 in. by $\frac{3}{4}$ in. of soft steel and 39 steel screen bars, Fig. 16, with $1\frac{1}{4}$ in. clear space between bars. In Iowa, the same sized bar is used, but the space between the bars is $1\frac{3}{8}$ in. In the other Western and Southern States there is at present no standard.

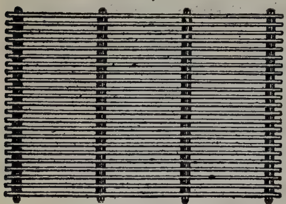


FIG. 15.

The standard nut-coal screen for Pennsylvania and Ohio is $\frac{3}{4}$ in. space, but $\frac{5}{8}$ in. is sometimes used and the nut screen is often varied to suit the special trade. At present very few pea screens are used, but if placed under a $\frac{3}{4}''$ nut screen, the space is from $\frac{5}{8}$ in. to $\frac{3}{8}$ in. In the Pittsburg region of Pennsylvania, all coal passing through $\frac{3}{4}''$ screen is called *slack*, while, on the Monongahela River, coal passing through $1\frac{1}{4}''$ screen is called *slack* and is used in stokers. Many companies are at present crushing their run-of-mine coal to make slack suitable for stokers.

It is difficult to classify bituminous coal by sizes, but as nearly as possible the following seem to be the standard: *Lump*, all coal passing over $1\frac{1}{4}''$ screen; *nut*, all coal passing through $1\frac{1}{4}''$ openings and over $\frac{3}{4}''$ openings; *slack*, all coal passing through $\frac{3}{4}''$ screen. If a pea-coal screen is used, all coal passing over $\frac{5}{8}''$, $\frac{1}{2}''$, and $\frac{3}{8}''$ would be pea coal, and that passing through $\frac{5}{8}''$, $\frac{1}{2}''$, or $\frac{3}{8}''$ would be slack.

Adjustable Bars.—The top of the bar is cylindrical and projects beyond the web which supports it, so that any lump which passes through the upper part will fall freely without jamming. The two ends of the bar are **V** shaped and fit into similarly shaped grooves, so that the bars can be set at distances from each other varying with the sum of the width of the bases of the triangles, the usual opening being about 4 in. These bars are generally 4 ft. long, but they can be of any size.

Finger bars are screen bars that are fixed at one end only, and the bars are narrower at the lower end than at the top, so that the spaces between them are wider at the bottom than at the top, thus giving less tendency for pieces of material to become wedged between the bars.

Movable or *oscillating bars* are screen bars that are attached to eccentrics at their lower ends, the eccentrics of adjoining bars being placed 180° apart. This movement throws the material forwards and the bars do not therefore require nearly the same inclination as fixed bars.

Shaking screens have an advantage in that the entire area of the screen is available for sizing, and hence a greater capacity can be obtained from a given area of screening surface. They also occupy less vertical height than a revolving screen. In coal breakers they are particularly applicable where the coal is wet and has a tendency to stick together. The principal disadvantage of the shaking screen is that the reciprocating motion imparts a vibration to the framing of the building. For anthracite coal, the screens usually have an angle or pitch of from $\frac{1}{2}$ in. to 2 in. per foot, the average being about $\frac{3}{4}$ in. per foot. These screens are run at from 90 to 280 shakes per minute, the average being about 200 shakes per minute, or 100 revolutions per minute for the cam-shaft. The throw of the eccentric or cam varies from 2 in. to 5 in.

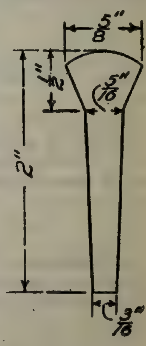


FIG. 16.

Similar screens are employed for sizing salt, but are usually placed at a much steeper incline and are frequently so hung that they have a combined rocking and swinging motion. Shaking screens are rarely employed in concentrating works on account of the fact that revolving screens can be hung in the upper part of the mill where they will not interfere with

other machinery, and hence the greater space that they occupy is not objectionable while they do the sizing satisfactorily without imparting jar to the structure.

The *capacities* of shaking screens operating on anthracite coal have been given as follows. The parties giving these figures advise the use of 140 R. P. M. for the cam-shaft.

For broken and egg coal, $\frac{1}{4}$ sq. ft. per ton for 10 hours.
For stove and chestnut coal, $\frac{1}{2}$ sq. ft. per ton for 10 hours.
For pea and buckwheat coal, $\frac{3}{4}$ sq. ft. for 10 hours.
For birdseye and rice, $1\frac{1}{4}$ sq. ft. per ton for 10 hours.

For sizing bituminous coal, inclined shaking screens are extensively used in certain sections, particularly in the Middle Western States. These screens are given a shaking motion by means of cams and connecting-rods, which make from 60 to 100 strokes per minute, the speed varying according to the amount of moisture in the coal. The throw of the eccentric is about 6 in. These screens are 7 ft. wide and vary in length according to the conditions in the tipple, no standard having been adopted. The average inclination at which they are set is 14°, though this angle varies under different conditions from 12° to 15°. The capacity of these screens running under the conditions given above is given by one maker as 2,000 to 2,500 tons per day of 8 hours. In one test lasting 8 hours, 2,000 tons of coal were passed over screens having perforated plates of the following dimensions:

56 sq. ft. with $\frac{3}{4}''$ perforations for making slack.
56 sq. ft. with $1\frac{1}{8}''$ perforations for making pea coal.
28 sq. ft. with $2\frac{1}{2}''$ perforations for making nut coal.
28 sq. ft. with $4\frac{1}{2}''$ perforations for making egg coal.

Another maker uses, for taking pea and dust from nut, and nut from lump, 50 to 60 sq. ft. of surface for each size, and to handle 600 to 800 tons in 8 hours he uses a $4\frac{1}{2}''$ travel and 120 to 130 shakes per minute, with the screen at an inclination of 15°.

Size of Mesh.—The following perforations have been adopted by two of the largest anthracite coal companies as the dimensions for the holes in shaking screens to produce sizes equivalent to those produced by revolving screens:

MESH FOR SHAKING SCREENS.

Kind of Coal.	Lehigh Valley Coal Co.	Phila. & Reading Coal & Iron Co.		Kind of Coal.
	Round.	Round.	Square.	
Steamboat		$5\frac{3}{8}''$	$5''$	Steamboat.
Lump	$4\frac{1}{2}''$	$4\frac{1}{2}''$	$4''$	Large broken.
Broken	$3\frac{1}{4}''$	$3\frac{1}{4}''$	$2\frac{3}{4}''$	Small broken.
Egg	$2\frac{5}{16}''$	$2\frac{1}{4}''$	$2''$	Egg.
Stove	$1\frac{5}{8}''$	$1\frac{1}{2}''$	$1\frac{3}{8}''$	Stove.
Chestnut	$\frac{15}{16}''$	$\frac{7}{8}''$	$\frac{3}{4}''$	Chestnut.
Pea	$\frac{5}{8}''$	$\frac{9}{16}''$	$\frac{1}{2}''$	Pea.
Buckwheat	$\frac{11}{32}''$	$\frac{5}{16}''$	$\frac{1}{4}''$	Buckwheat.
Rice	$\frac{3}{16}''$	$\frac{3}{16}''$	$\frac{1}{8}''$	Rice.

Revolving Screens, or Trommels.—The screen is placed about the periphery of a cylinder or frustum of a cone. The material to be sized is introduced at one end; the small size passes through the screen, and the other size is discharged from the other end. If the form is cylindrical, it is necessary to place the supporting shaft on an incline so that the material will advance toward the discharge end. The inclination of the shaft determines the rapidity with which the material will be carried through the screen. The advantage of the conical screen is that the shaft is horizontal and hence the bearings are simpler. This a very decided advantage in many mills where the machinery must of necessity be crowded into a minimum space and be hard to get at.

Pentagonal screens, or screens having some other number of flat sides, are sometimes employed. These are run at a very much more rapid rate than circular screens, it being intended that the material shall be thrown or dashed against the screen surfaces to break it or to loosen adhering clay

or dirt. The shaft is sometimes hollow, and streams of water from this hollow shaft wash the material as it is being screened.

Revolving screens are frequently jacketed, that is, two or more screens are placed concentrically about the same shaft, the inmost one being the coarsest, and each succeeding screen serving to make additional separations. This method reduces the space necessary for a given amount of sizing machinery. In other cases, a long cylindrical screen has a coarse mesh near its discharge end and finer mesh near the entrance end, thus making two or more through products as well as the overproduct. The disadvantage of jacketed screens is that the necessarily slow speed of the inmost screen reduces the capacity of the entire combination, so that if rapid work is essential, it is better to use fairly large-diameter screens placed one after the other in place of jacketed screens. Another disadvantage is that, to renew the inner jackets, it is often necessary to remove the outer ones.

The disadvantages of having two or more sizes of wire cloth on one screen are that the fine-meshed screen near the head is worn out rapidly, as all the material both coarse and fine passes over it, while, when separate screens are employed, each screen has to deal only with its through or over sized product, all coarser material having been removed.

Speed.—The periphery of a revolving screen should travel about 200 ft. per minute. In the case of very fine material, screens are sometimes run faster than this.

The following have been adopted as standard speeds for screens by one of the largest anthracite coal companies:

SPEED OF SCREENS.

	Rev. per Minute.		*Rev. per Minute.*
Mud screens	8.87	Big screens	8.52
Counter mud screens	15.49	Pony screens	10.87
Cast-iron screens	11.25	Buckwheat screens	15.30

Duty of Anthracite Screens.—The following table gives the number of square feet of screen surface required for a given duty in the case of revolving screens working upon anthracite coal:

Egg coal,	1 ton per 1 sq. ft. per 10 hours.
Stove coal,	1 ton per $1\frac{1}{4}$ sq. ft. per 10 hours.
Chestnut coal,	1 ton per $1\frac{1}{2}$ sq. ft. per 10 hours.
Pea coal,	1 ton per 2 sq. ft. per 10 hours.
Buckwheat coal,	1 ton per $2\frac{3}{4}$ sq. ft. per 10 hours.
Rice coal,	1 ton per $3\frac{3}{4}$ sq. ft. per 10 hours.
Culm,	1 ton per 5 sq. ft. per 10 hours.

These figures may be reduced from 20% to 30% for very dry or wash coal.

Revolving Screen Mesh for Anthracite.—A standard mesh for revolving screens for sizing anthracite coal was adopted some years ago, but it is only approximately adhered to and a considerable variation from the standard is found throughout the anthracite region.

The following are probably as nearly standard meshes for revolving screens for sizing anthracite coal as can be given:

MESH FOR SIZING COAL.

Culm	passes through $\frac{3}{32}''$ mesh.
Birdseye	passes over $\frac{1}{4}''$ mesh, and through $\frac{5}{16}''$ mesh.
Buckwheat	passes over $\frac{1}{4}''$ mesh, and through $\frac{1}{2}''$ mesh.
Pea	passes over $\frac{1}{2}''$ mesh, and through $\frac{3}{4}''$ mesh.
Chestnut	passes over $\frac{3}{4}''$ mesh, and through $1\frac{3}{8}''$ mesh.
Stove	passes over $1\frac{3}{8}''$ mesh, and through 2″ mesh.
Egg	passes over 2″ mesh, and through $2\frac{3}{4}''$ mesh.
*Grate	passes over $2\frac{3}{4}''$ mesh, and out end of screen.
*Special grate	passes over 3″ mesh, and out end of screen.
*Special steamboat	passes over 3″ bars, and through 6″ bars.

Hydraulic Classifiers.—The separation of materials by this class of machinery depends upon the law of equally falling bodies, which may be stated as follows: *Bodies falling free in a fluid, fall at a speed proportional to their weight divided by the resistance.* From this it will be seen that small masses of a heavy mineral will fall as rapidly as large masses of a light mineral, owing to the fact that the weight increases as the volume and the

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*These sizes and "lump" size are seldom made, and there is no uniformity whatever in the sizes called by these names.

resistance only as the area, so that if a quantity of galena and quartz of various sizes were introduced into water, it would settle into approximate layers, each composed of relatively large pieces of quartz and relatively small pieces of galena. This same action would be true in the case of any

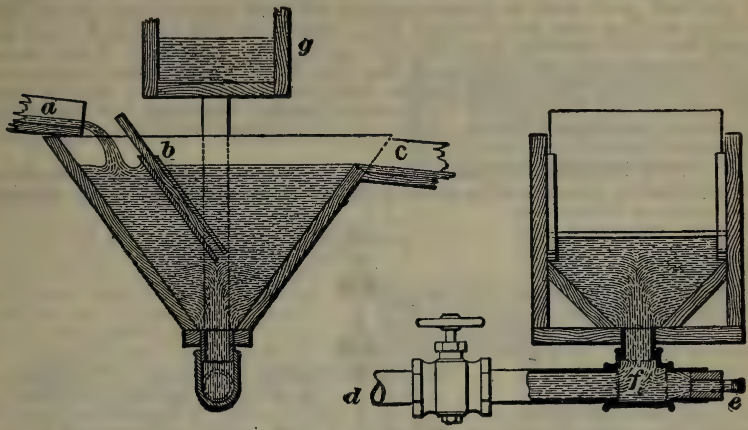


FIG. 17.

minerals differing in specific gravity. The principal representatives of the hydraulic classifying machines are the Spitzkasten and Spitzlutten.

The **Spitzkasten** consists of a series of pyramidal boxes, one of which is shown in Fig. 17. The material enters the box at *a*, passes down under the diving board *b*, and discharges into the next box through the trough *c*. At the bottom of the box, water is introduced through the pipe *d* from the launder *g* in such quantity as to more than supply the opening or spigot *e*. The heavy particles of mineral settle against this rising stream of water into the elbow *f*, from which they are washed out through *e*. Each succeeding box is made larger than the preceding, and the rising current is so regulated that a different product will settle out in each.

The **Spitzlutten** is a **V**-shaped box, inside of which is set another **V** having the same slope, the material flowing down between the two **V**'s on one side and up and out on the other. The distance between the **V**'s can be regulated, as can also the rising current of water, thus obtaining the separation desired.

Many other forms of separators, all depending on this same principle, have been brought out, some having a conical form, some being arranged in the form of troughs, and others as boxes of various shapes.

The **Calumet classifier**, Fig. 18, consists of a series of boxes or pockets in the bottom of a gradually widening trough. Wash water enters through a pipe *a* and discharges directly against the discharge spigot *d*, which is however not large enough to carry all the water off directly, hence it twirls and eddies in the bottom of the box so that only the heaviest particles having weight enough to settle in this disturbed water pass out through the spigot. A shield *c* reflects upward currents and confines the agitation to the bottom. The pulp flowing in the direction of the arrows is deflected downwards by the boards *s*.

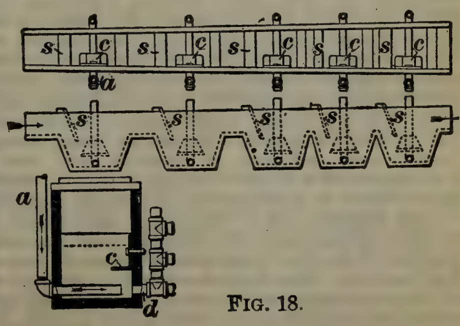


FIG. 18.

The **settling boxes** employed for mills are really a form of hydraulic classifier. They are usually very large **V**-shaped boxes provided with a diving board similar to that shown at *b* in Fig. 17, but no current of water is

introduced. In some cases a small stream of the heavy muds or concentrates is kept continually flowing from the bottom, while in others they are drawn off intermittently. One very important point to be observed in settling boxes is that the settling action depends on the arresting of the current, and with a given amount of floor space, very much more efficient settling can be obtained from two boxes placed side by side and having half the material pass through each than from two boxes placed in series, and that the width of the box is of vastly more importance than the length. The depth is also fairly important, and a diving board must always be introduced to prevent surface currents. If the boxes are properly arranged, nearly all the solid material will be settled out of the water.

The **Jeffrey-Robinson coal washer,** Fig. 19, which operates on the principle of the Spitzkasten, consists of a steel chamber *B* in the form of an inverted cone, inside of which are projecting arms and stirring plates *C, C* revolved by a driving gear *A*. The water supply enters at the bottom from the water pipe *P* through perforations *M*. The coal is introduced through a chute *S* and is kept in a continual state of agitation by the current of water, and being lighter than the impurities, it passes out through the overflow *K* onto the conveyors *E, F* and through the chutes *X, X*, while the water and sludge drain through the hopper into the sludge tank *G*, whence, if necessary, the same water can be again pumped by the pulsometer *H* back into the washer. (As mentioned elsewhere, it is poor practice to use this water over again when it is desired to decrease the percentage of sulphur in the washed product as greatly as possible.)

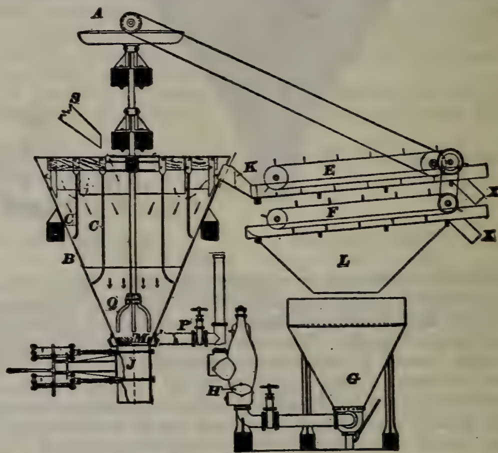


FIG. 19.

The heavy impurities sink to the bottom into the chamber *J* and when this is full the upper of the two valves shown is closed and the lower valve is opened to discharge the refuse.

The following data in regard to one of these washers is given by Mr. J. J. Ormsbee in the Transactions of the A. I. M. E. These results were obtained at the Pratt Mines, Alabama, with a plant having a nominal capacity of 400 tons per day. By washing slack that passed between screen bars spaced ¾ in. in the clear, the washed coal contained 42% less ash than the unwashed coal, the reduction in sulphur was 15%, while the volatile matter was increased 4%, and the fixed carbon 5%. With coal passing over ⅜″ perforations, the results were a reduction of 48% in ash, 15% in sulphur, and a gain of 5% in volatile matter and 6% fixed carbon. These results indicate that the washer is better adapted to large sizes than to fines. The amount of water used per ton of washed coal was 35.1 gallons and the cost was 2.25 cents per ton for washing 400 tons, itemized as follows: Labor at washer, $2.00; labor at boiler, fuel, etc., $4.00; repairs and supplies, $3.00; total, $9.00.

Log Washer.—For removing clay from ores or other material, the log washer illustrated in Fig. 20 has proved itself to be efficient. Either single or double logs are employed, the form shown being the double-log washer. The logs work over troughs which have a slight inclination, so that the water will flow from one end to the other. Water is introduced at the upper end and discharged at the lower end. The material to be washed is introduced near the lower end and is fed up against the water by spiral arms or plates fixed about the logs, as shown in the illustration. As the material is advanced, the clay or other sticky substance is broken up, washed away, and discharged at the lower end with the wash water.

These washers have been extensively employed for cleaning iron ores occurring as rather hard masses in clay.

There is no general standard size of these washers, but most of the double-log washers for both steel and wood logs are the same, except in length of logs, the washer box being 7 ft. 4 in. wide, 2 ft. deep at discharge end, and 4 ft. deep at receiving end. The length of logs varies from 20 to 30 ft. The logs are generally given an elevation of 1 in. in 1 ft., and sometimes $1\frac{1}{4}$ in. in 1 ft.

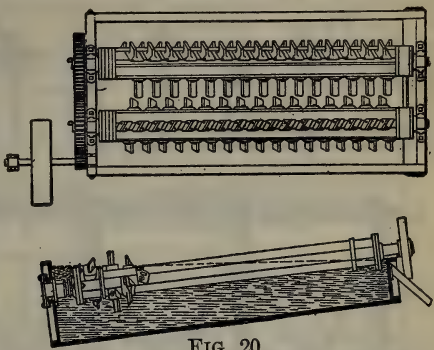


FIG. 20.

The capacity of an ore washer depends very much on the quality of the material, averaging for one pair of logs from 100 tons per day, when the matrix is of a clayey nature, to 350 tons with loose sandy material. The capacity of a washer is based on the amount of material from the mines it will put through more than the tonnage of clean ore, and this amount varies from 500 to 1,000 yd. per 10 hours. The amount of water used varies from 300 to 500 gal. per minute. The total expense for labor and fuel, including the water supply, varies from 5 cents to 25 cents per ton of ore, averaging possibly 10 cents per ton.

The **Scaife trough washer** consists of a semicircular iron trough 2 ft. in diameter and 24 ft. long. Inside is a series of fixed dams or partitions that can be made higher or lower, as required, by means of plates. A shaft running the entire length of the trough and turning in babbitted journals carries a number of stirring arms or forks and is given a reciprocating motion by a connecting-rod attached to a driving pulley at its center. The coal is fed with water at the upper end of the trough, and by the action of the flowing water and the agitation of the arms, the slate, pyrites, and other impurities settle at the bottom and are caught behind the dams, while the clean coal passes over the dams and out at the lower end of the trough. When the spaces behind the dams are filled, feeding is stopped and the refuse in the dams quickly dumped. This form of washer is particularly successful with coal mixed with fireclay. One washer handles from 75 to 100 tons of coal per day, and one man can attend to six washers. Each washer requires less than 1 H. P. to operate it. The larger the coal, the greater must be the slope and the quantity of water used.

Jigs.—This is a general term applied to that class of concentrating machines in which the separation of the mineral from the gangue takes place on a screen or bed of material and is effected by pulsating up-and-down currents of a fluid medium.

There are a number of different methods in use for driving the pistons that cause the pulsations of the water in jigs. Some of these use plain eccentrics, giving the same time to both the up and the down strokes of the pistons, while others employ special arrangements of parts, which give a quick down stroke and a slow up stroke, thus allowing the water ample time to work its way back through the bed without any sucking action from the piston. This tends to make a better separation in some cases than the use of the plain eccentrics.

Stationary Screen Jigs.—This class is illustrated by Fig. 21, which shows a 3-compartment jig. The separation takes place on screens supported on wooden frames *g*, and is effected by moving the water in each compartment so that it ascends through the screen, lifting the mineral and allowing it to settle again, thus giving the material an opportunity to arrange itself according to the law of equally falling particles. Each compartment is composed of two separate parts, one containing the screen on the support *g* and the other adjoining it and arranged so that the piston in it may impart the necessary pulsations to the water. These pistons are usually loose fitting and are operated by the eccentrics *e* on the shaft *s*. Jigs operating on coarse ore should be fed with approximately sized material, when the ore will accumulate near the bottom on the screen and the barren portion or gangue will

be carried over the discharge. Formerly, the concentrates were discharged from jigs intermittently by digging out the tailings first, then the middlings, which are composed of pieces containing some ore and some gangue, and then the concentrates, but it has been found that the concentrates will flow over the screen like a liquid of comparatively heavy specific gravity,

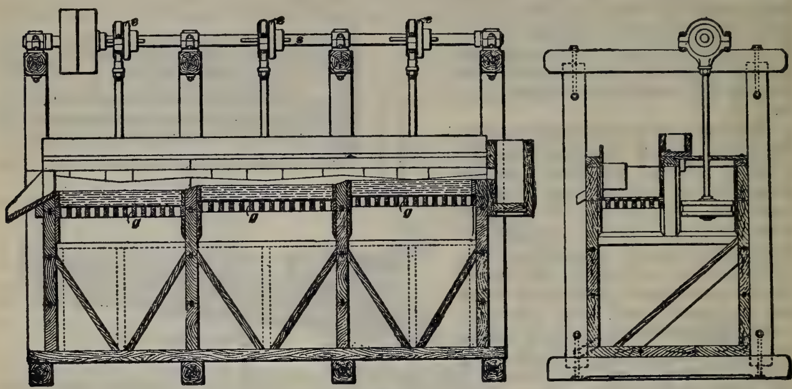


FIG. 21.

Advantage has been taken of this fact in the design of several forms of jig discharges.

The **Heberle gate**, Fig. 22, acts as follows: a is a **U**-shaped shield fastened against the inside of the jig and held in place by a band b, the ends of which are drawn down into the form of bolts and pass through the sides of the jig, where they are secured with suitable nuts. The shield a may be raised or lowered by loosening the band b. The discharge takes place through the opening f in the side of the jig, the size and position of the opening being regulated by slides c. The concentrates k rest on the screen e supported by a grating d, while the tailings i occupy a higher position. The shield a prevents the tailings from flowing out through the opening f, while the concentrates flow along the screen and rise to a height somewhat lower than the top of the tailings in the jig, when they are discharged through the opening f over the spout h, as shown at p. The tailings are usually discharged over the dam at the end of the jig, and in some cases a third discharge is provided of the Heberle-gate pattern and so arranged that the middlings will flow out through it and discharge separately from the tailings and the concentrates.

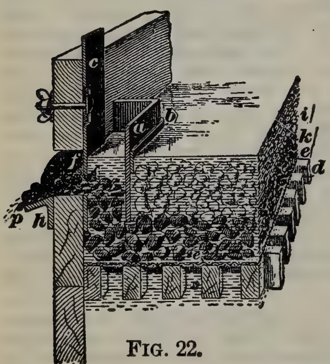


FIG. 22.

In the case of jigs handling fine material, the material may be sorted by hydraulic classifiers and then introduced on to the jigs. In this class the mineral will be in the form of relatively small pieces, while the gangue will occur as relatively large pieces. Advantage may be taken of this fact by regulating the mesh of the jig screen so that the concentrates will pass through into the space below the screen, commonly called the *hutch*, while the tailings will pass over the tailing dam. In some cases the gate discharge is employed on the side to remove the middlings. The middlings are recrushed and treated on other machines. This form of concentration has been used very largely in connection with the Lake Superior copper ores, the values of which occur as metallic copper in a relatively light gangue, and also in concentrating tin ores that occur in the light gangue containing considerable mica.

Theory of Jigging.—By far the most exhaustive investigations on the theory of jigging carried on in America are those of Prof. Robert H. Richards, of the Massachusetts Institute of Technology, and the greater part of the following theoretical discussion is based on his several papers published in the Transactions of the American Institute of Mining Engineers.

Four laws of jigging are given by the several authorities: (1) The law of equal settling particles, under free settling conditions; (2) the law of interstitial currents, or settling under hindered settling conditions; (3) the law of acceleration; (4) the law of suction.

The first of these is the most important, but the others are elements that cannot be disregarded in connection with jigging.

Equal Settling Particles.—Rittinger gives the following formulas to represent the relation between diameter of grains and rate of falling in water for irregularly shaped grains:

$$V = 2.73\sqrt{D(\delta - 1)}, \text{ for roundish grains;}$$
$$V = 2.44\sqrt{D(\delta - 1)}, \text{ for average grains;}$$
$$V = 2.37\sqrt{D(\delta - 1)}, \text{ for long grains;}$$
$$V = 1.92\sqrt{D(\delta - 1)}, \text{ for flat grains,}$$

in which V = velocity in meters per second; D = diameter of particles in meters, and δ = specific gravity of the minerals.

By means of these different formulas, the ratios of the diameters of different particles that will be equal settling in water can be computed. Professor Richards has not found these formulas to hold in all cases in practice, and, as the result of elaborate experiments, he gives the following table:

EQUAL SETTLING FACTORS OR MULTIPLIERS.

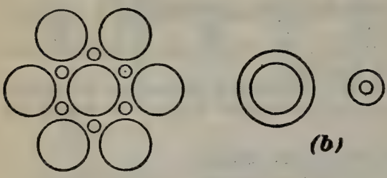
Table of equal settling factors or multipliers for obtaining the diameter of a quartz grain that will be equal settling under free settling conditions with the mineral specified.

	Specific Gravity.	Velocity in Inches per Second.									Rittinger's Multipliers.
		1	2	3	4	5	6	7	8	9	
		Author's Multipliers.									
Anthracite	1.473	.500	.352	.225	.213						.288
Epidote	3.380	1.57	1.35	1.05	1.13	1.50	1.61	1.56	1.56	1.47	1.45
Sphalerite	4.046		1.46	1.05	1.17	1.62	1.64	1.68	1.66	1.56	1.85
Pyrrhotite	4.508		1.73	1.29	1.48	2.00	2.22	2.26	2.13	2.08	2.14
Chalcocite	5.334		1.90	1.47	1.62	2.07	2.28	2.41	2.44	2.17	2.64
Arsenopyrite	5.627		1.90	1.57	1.89	2.42	2.56	2.72	2.84	2.94	2.82
Cassiterite	6.261		2.11	1.79	2.00	2.73	2.93	3.03	3.05	3.12	3.32
Anitmony	6.706		2.71	2.00	2.00	2.73	2.93	3.03	2.98	3.00	3.48
Wolframite	6.937		2.71	1.83	2.07	2.86	3.04	3.21	3.28	3.26	3.64
Galena	7.856		2.71	1.83	2.26	3.00	3.42	3.65	3.76	3.75	4.01
Copper	8.479		2.71	2.00	2.36	3.00	3.20	3.58	3.76	3.75	4.56
Quartz	2.640										

The significance of the above table is as follows: If a piece of anthracite of a certain size falls in water with a velocity of 4 in. per second, a piece of quartz 0.213 times the diameter of the anthracite will fall with the same velocity. If a piece of copper of a certain size falls with a velocity of 7 in. per second, a piece of quartz 3.58 times as large as the copper will fall with the same velocity.

Interstitial Currents, or Law of Settling Under Hindered Settling Conditions. If d equals the diameter of a falling particle, and D that of the tube in which it falls, the larger the fraction $\frac{d}{D}$, the greater will be the retardation or loss

of velocity by the particle. When this fraction equals 1, the particle stops. If, in Fig. 23 (*a*), the larger circles represent particles of quartz and the smaller circles equal settling particles of galena, then if these mixed particles are settling together or are held in suspension by a rising current of water, each particle may be considered to be falling in a tube, the walls of which consist of the surrounding particles. Substituting a circle in each case for the imaginary tube, we have Fig. 23 (*b*) representing the conditions for galena and quartz, the outer circle in each case representing the imaginary tube. Evidently, $\frac{d}{D}$ is much smaller for the galena than for the quartz, and it will therefore be much less impeded in its fall than the quartz; hence, the particles of galena found adjacent to the particles of quartz will be smaller than the ratio that the law of equal settling particles under free settling conditions would indicate. Application of this principle is found when a mass of grains is subjected to a rising current of sufficient force to rearrange the grains according to their settling power and the grains are said to be treated under hindered settling conditions, as on the bed of a jig.



(*a*) (*b*) FIG. 23.

Interstitial factors, or multipliers for obtaining the diameter of the particle of quartz that under hindered settling conditions will be found adjacent to and in equilibrium with the particle of the mineral specified, are the following:

Copper	8.598	Cassiterite	4.698	Pyrrhotite	2.808
Galena	5.842	Arsenopyrite	3.737	Sphalerite	2.127
Wolframite	5.155	Chalcocite	3.115	Epidote	1.628
Antimony	4.897	Magnetite	2.808	Anthracite	.1782

These signify that, after pulsion has done its work on a jig bed, for example, where quartz and anthracite are being jigged, the grains will be so arranged that the grains of quartz are .1782 times the diameter of the grains of anthracite that are adjacent to and in equilibrium with them.

Acceleration.—A particle of galena that is equal settling to the particle of quartz reaches its maximum velocity in perhaps $\frac{1}{10}$ the time required by the quartz. The oft-repeated pulsations of a jig, therefore, give the galena particles a decided advantage over the quartz, placing beside the quartz, when equilibrium is reached, a much smaller particle of galena than we should expect according to the law of equal settling particles.

Suction acts to draw down through the screen small grains, mainly of the heavier mineral, which are distributed among large grains. It increases as the length of plunger stroke, with the difference in specific gravity of the two minerals, and with the diminishing of the thickness of the bed on the sieve, whether of the heavier mineral only or of both minerals. The law of suction seems to be that jigging is greatly hindered by strong suction where the two minerals are nearly of the same size, the quickest and best work then being done with no suction; but when the two minerals differ much in size of particles, the quartz being the larger, strong suction is not only a great advantage, but may be necessary to get any separation at all. Experiments have indicated an approximate boundary between grains that are helped and those that are hindered by suction; namely, if the diameter of the quartz particles is equal to or greater than 3.52 times the diameter of the other mineral particles, then separation is helped by suction; if less, separation is hindered. This value 3.52 (obtained by dividing .0683 by .0195) is approximate only, and it will differ with the fracture of the quartz under consideration; if the quartz grains are much flattened, it will have a large value.

Eccentric jigs invariably spend more time on pulsion than accelerated jigs. Is it not fair to conclude that the eccentric jigs are better adapted for treating sands that require the most pulsion? Such sands are the sized products from the trommel and the first spigot of the hydraulic classifier. On the other hand, may not the long-protracted mild suction of the accelerated jig be best adapted to the treatment of such products as require primary suction for their separation; for example, the second spigot and

the following spigots of the hydraulic classifier? This may be the reason that the Collom jig has found so great favor at Lake Superior and at Anaconda, where all the jigging is done on true hydraulic-separator products, except the first sieve of the first jig. We should, however, bear in mind that the somewhat harsh suction of the eccentric jig can be made milder by increasing the hydraulic water. This will diminish the hardening of the bed, but it cannot lengthen the time of suction, so as to secure the condition as presented in this particular by the accelerated jigs.

Two extreme suggestions arise from a contemplation of the experiments we have carried on: (1) On closely sized products, an accelerated jig should be run backwards, to lengthen out the pulsion period, which is the only period that does any work; and (2) the accelerated jig should be run forwards on the spigot products of the hydraulic separator, to increase the period of suction.

In the way of the first suggestion, there are two difficulties, either of which may cancel the advantage: *first*, the violent downward motion of the quick return will tend to "blind up" the sieve; and, *second*, the same action will tend to pulverize a soft mineral like galena.

Professor Richards summarizes his experiments in connection with jigging as follows: The two chief reactions of jigging are pulsion and suction. The effect of pulsion depends on the laws of interstitial currents, or of equal settling particles, under hindered settling conditions. The chief function of pulsion is to save the larger grains of the heavier mineral, or the grains that settle faster and farther than the waste. The effect of suction depends on the interstitial factor of the minerals to be separated. If this factor is greater than 3.70, suction will be efficient and rapid. If the factor is less than 3.70, suction will be much hampered and hindered. The use of a long stroke will help to overcome this difficulty. The chief function of suction is to save the particles that are too small to be saved by the law of interstitial currents, acting through the pulsion of the jig. For jigging mixed sizes, pulsion with full suction should be used. For jigging closely sized products, pulsion with a minimum of suction should be used.

The degree of sizing needed as preparation for jigging, if perfect work is desired, depends on the interstitial factor of the minerals to be separated. If the factor is above 3.70 (assuming this value to be sufficiently proved), then sizing is simply a matter of convenience. The fine slimes should of course be removed; and if it is more convenient to send egg size, nut size, pea size, and sand size, each to its own jig, the suitable screens should be provided for this purpose and a hydraulic separator for grading the finest sizes. But if, on the other hand, the factor is below 3.70, then the jigging of mixed sizes cannot give perfectly clean work, and the separation will be approximate only. To effect the most perfect separation, close sizing must be adopted, and the closer the sizes are to one another, the more rapid and perfect will the jigging be. There may be conditions where the jigging of mixed sizes of this class will be considered sufficiently satisfactory, as an expedient, under the circumstances.

Removal of Sulphur From Coal.—The object of washing coal is to remove the slate and pyrites, thus reducing the amount of ash and sulphur. Many forms of washers easily and cheaply reduce the slate from 20% in the coal to 8% of ash in the coke, but it is much more difficult to reduce 4% of sulphur in the coal to 1% or less of sulphur in the coke. Sulphur occurs in the coal in three forms, as hydrogen sulphide, calcium sulphate, and pyrite. The first is volatile and is removed in coking, the second cannot usually be removed by preliminary treatment, and it is the removal of the third form with which washing has to do. The presence of water in the coke ovens apparently assists the removal of the sulphur; but wet coals require a longer time for coking than dry, and, therefore, pyrite should be removed as far as practicable before charging the coal into the coke ovens. The pyrite in coal as it comes from the mine seems to be in particles even finer than those of the coal dust. This impalpable powder or flour pyrites floats in air or water. This being the case, the common practice of using the water over and over again in a washery cannot give the best results in the removal of sulphur, as some flour pyrites will be carried back each time and remain with the washed coal. Experiments made by Mr. C. C. Upham, of New York City, show that the critical size at which an almost complete division of the coal and pyrites takes place varies with coals from different districts and beds, and in laying out coal-washing plants, the proper fineness of crushing should be determined beforehand by careful experiment.

Preparation of Anthracite.—The method of preparing anthracite coal is clearly shown, graphically, by the diagram below. This consists in screening the coal over bars and through revolving or over shaking screens, together with breaking it with rolls to produce the required market size.

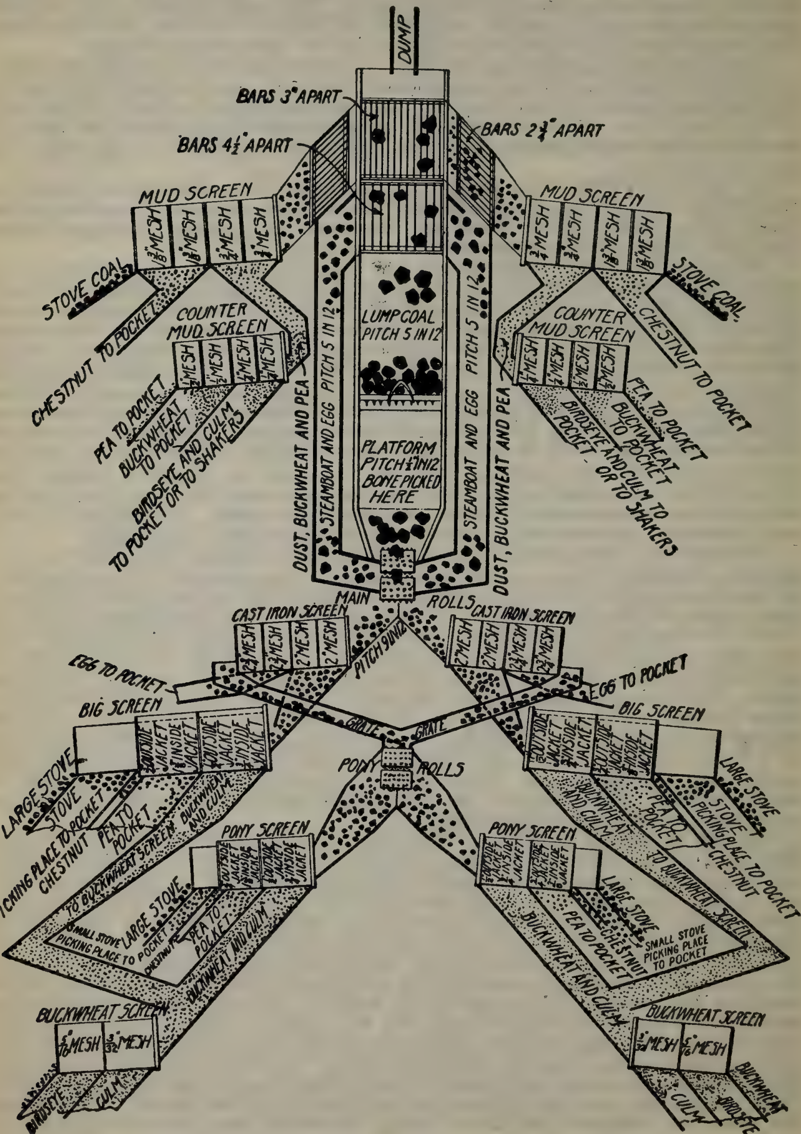


DIAGRAM SHOWING METHOD OF PREPARING ANTHRACITE COAL.

The large lumps of slate and other impurities are separated by hand on the platform near the dump, while the smaller portions are picked out by automatic pickers or by hand by boys or old men seated along the chutes leading to the shipping pockets or bins. The smaller sizes are cleaned by jigging.

HANDLING OF MATERIAL.

Anthracite Coal.—The following may be taken as average figures for the angle or grade of chutes for anthracite coal, to be used where the chutes are lined with sheet steel: For broken or egg coal, $2\frac{1}{2}$ in. per ft.; for stove or chestnut coal, $3\frac{1}{2}$ in. per ft.; for pea coal, $4\frac{1}{4}$ in. per ft.; for buckwheat coal, 6 in. per ft.; for rice coal, 7 in. per ft.; for culm, 8 in. per ft.

If the coal is to start on the chute, 1 in. per ft. should be added to each of the above figures; while if the chutes are lined with manganese bronze in place of steel, the above figures can be reduced 1 in. per ft. for coal in motion, or would remain as in the table to start the coal. When the run of mine is to be handled, as in the main chute, at the head of the breaker, the angle should be not less than 5 in. per ft., or practically $22\frac{1}{2}°$ from the horizontal. If chutes for hard coal are lined with glass, the angle can be reduced from 30% to 50%, depending somewhat on the nature of the coal. In all cases, the flatter the coal, the steeper the angle must be, on account of the large friction surfaces exposed, compared with the weight of the piece. If chutes are lined with cast iron, the angle should be about the same as that employed for steel, though sometimes a slightly greater angle is allowed.

The following table is printed through the courtesy of the Link-Belt Engineering Co., Philadelphia, Pa.:

PITCH AT WHICH ANTHRACITE COAL WILL RUN, IN INCHES PER FOOT.

Kind of Coal.	Sheet Iron.		Cast Iron.	Glass.		Glass.	
	Start on.	Continue on.	Start on.	Start on.	Continue on.	Start on.	Continue on.
	Dry.					Wet.	
Broken slate	$5\frac{1}{4}$	$4\frac{3}{8}$	$5\frac{3}{8}$	$3\frac{1}{4}$	3		
Dry egg slate	$5\frac{1}{4}$	$4\frac{3}{8}$	$5\frac{1}{4}$	$3\frac{1}{4}$	3		
Dry stove slate	$5\frac{1}{4}$	$4\frac{3}{8}$	$5\frac{1}{4}$	$3\frac{1}{4}$	3		
Dry chestnut slate	[illegible]	$4\frac{3}{8}$	$5\frac{1}{4}$	$3\frac{1}{4}$	3		
Broken coal				$2\frac{5}{8}$	$2\frac{1}{4}$		
Egg coal	$3\frac{3}{8}$	3	$3\frac{7}{8}$	$2\frac{5}{8}$	$2\frac{1}{4}$	$2\frac{1}{4}$	$1\frac{3}{4}$
Stove coal	$4\frac{3}{4}$	$4\frac{1}{4}$	$4\frac{3}{4}$	3	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{8}$
Chestnut coal	$4\frac{3}{4}$	$4\frac{1}{4}$	$4\frac{3}{4}$	3	$2\frac{1}{2}$	3	$2\frac{1}{2}$
Pea coal	$5\frac{1}{2}$	5	$5\frac{3}{4}$	$3\frac{1}{4}$	$2\frac{1}{2}$	3	$2\frac{9}{16}$
Buckwheat No. 1				$3\frac{5}{8}$	$3\frac{1}{8}$	$3\frac{1}{2}$	$3\frac{1}{8}$
Buckwheat No. 2				$3\frac{3}{4}$	$3\frac{1}{4}$	$3\frac{3}{4}$	$3\frac{1}{4}$
Buckwheat No. 3				$4\frac{3}{8}$	$3\frac{3}{8}$	$4\frac{7}{8}$	$4\frac{1}{8}$
Buckwheat No. 4				$4\frac{7}{8}$	$4\frac{1}{8}$	$4\frac{7}{8}$	$4\frac{1}{3}$

Bituminous Coal—When the run of mine is to be handled, the angle of the chutes should be from 35° to 45° from the horizontal, or from $8\frac{1}{2}$ in. to 12 in. per ft. If the coal is wet, the angle should always be steeper, and coarse coal will slide on a flatter angle than slack or fine coal.

Ore, Rock, Etc.—For coarse fairly dry ore, i. e., from 2 in. or 3 in. size up, chutes may have an angle of 45°, or if the material is always to be in motion, the ore will sometimes slide on 40°. For fine ore or run of mine, the chutes should have an angle of 50° from the horizontal or practically 14 in. vertical to 1 ft. horizontal.

Flumes and Launders.—Water flumes are given grades varying from 4 or 5 to 20 or 30 ft. per mile, depending on the surface of the ground and the amount of water to be carried. Practical results have demonstrated the fact that in ordinary ground the water should travel at the rate of from 180 to 200 ft. per minute.

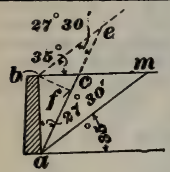
Where rather coarse stuff is to be carried through launders in a mill with a comparatively small amount of water, an angle of 2 in. per ft. should be used. With an excess of water, 1 in. per ft. will be ample. The spouting for vanners or launders from trommels carrying rather fine material should have a grade of about 2 in. per ft. In placer mining, the minimum grade

for the sluice should not be less than ¼ in. per ft., or about 4⅛ in. per rod. Experiments made in river gravel have shown that with a grade of from 1 in 20 to 1 in 25, 60 cu. ft. per min. will wash 140 to 175 cu. yd. per day of 24 hours.

No absolutely definite figures can be given on this subject, owing to the fact that the nature of the ore plays an important part, and while angular quartzose ore can be transported at a comparatively flat angle, it may be necessary to use quite a steep angle if the material is of a clayey nature or contains many large flat plates, exposing large friction surfaces when compared to the mass of the pieces.

The following tables are printed through the courtesy of the Link-Belt Engineering Co., Philadelphia, Pa.:

HORIZONTAL PRESSURE EXERTED BY BITUMINOUS COAL AGAINST VERTICAL RETAINING WALLS PER FOOT OF LENGTH.



Surface horizontal $\begin{cases}\text{total pressure} & = 6.37\,d^2 \\ \text{pressure lowest ft.} & = 6.37(2\,d-1)\end{cases}$

Surface sloping $\begin{cases}\text{total pressure} & = 10\,d^2 \\ \text{pressure lowest ft.} & = 10(2\,d-1)\end{cases}$

Angle of repose = 35°

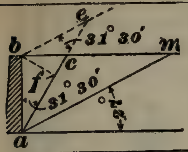
d = height of wall in feet or ab

BITUMINOUS.

Depth *b a* in Ft.	Horizontal Surface. *b m.* Total Pressure.	Horizontal Surface. *b m.* Pressure Lowest Ft.	Sloping Surface. *b e.* Total Pressure.	Sloping Surface. *b e.* Pressure Lowest Ft.	Depth *b a* in Ft.	Horizontal Surface. *b m.* Total Pressure.	Horizontal Surface. *b m.* Pressure Lowest Ft.	Sloping Surface. *b e.* Total Pressure.	Sloping Surface. *b e.* Pressure Lowest Ft.
1	6.4	6.4	10	10	26	4,305	325	6,760	510
2	25.0	19.0	40	30	27	4,641	338	7,290	530
3	57.0	32.0	90	50	28	4,993	350	7,840	550
4	102.0	45.0	160	70	29	5,358	363	8,410	570
5	159.0	57.0	250	90	30	5,733	376	9,000	590
6	229.0	70.0	360	110	31	6,122	389	9,610	610
7	312.0	83.0	490	130	32	6,523	401	10,240	630
8	407.0	96.0	640	150	33	6,935	414	10,890	650
9	516.0	108.0	810	170	34	7,362	427	11,560	670
10	637.0	121.0	1,000	190	35	7,778	440	12,250	690
11	770.0	134.0	1,210	210	36	8,253	452	12,960	710
12	917.0	146.0	1,440	230	37	8,754	465	13,690	730
13	1,076.0	159.0	1,690	250	38	9,193	478	14,440	750
14	1,248.0	172.0	1,960	270	39	9,682	490	15,210	770
15	1,433.0	185.0	2,250	290	40	10,192	503	16,000	790
16	1,630.0	197.0	2,560	310	41	10,669	516	16,810	810
17	1,840.0	210.0	2,890	330	42	11,236	529	17,640	830
18	2,063.0	223.0	3,240	350	43	11,797	541	18,490	850
19	2,298.0	236.0	3,610	370	44	12,331	554	19,360	870
20	2,548.0	248.0	4,000	390	45	12,968	567	20,250	890
21	2,809.0	261.0	4,410	410	46	13,478	580	21,160	910
22	3,083.0	274.0	4,840	430	47	14,100	592	22,090	930
23	3,369.0	287.0	5,290	450	48	14,679	605	23,040	950
24	3,669.0	299.0	5,760	470	49	15,275	618	24,010	970
25	3,981.0	312.0	6,250	490	50	15,925	631	25,000	990

Weight of coal = 47 lb. per cu. ft.

Horizontal Pressure Exerted by Anthracite Coal Against Vertical Retaining Walls per Foot of Length.



Surface horizontal { total pressure $= 9.78\,d^2$
pressure lowest ft. $= 9.78(2\,d-1)$

Surface sloping { total pressure $= 14.22\,d^2$
pressure lowest ft. $= 14.22(2\,d-1)$

Angle of repose $= 27°$

d = height of wall in feet.

ANTHRACITE.

Depth *b a* in Ft.	Horizontal Surface. *b m.* Total Pressure.	Horizontal Surface. *b m.* Pressure Lowest Ft.	Sloping Surface. *b e.* Total Pressure.	Sloping Surface. *b e.* Pressure Lowest Ft.	Depth *b a* in Ft.	Horizontal Surface. *b m.* Total Pressure.	Horizontal Surface. *b m.* Pressure Lowest Ft.	Sloping Surface. *b e.* Total Pressure.	Sloping Surface. *b e.* Pressure Lowest Ft.
1	9.78	9.78	14.22	14.22	26	6,611.1	498.78	9,612.8	725.21
2	39.12	29.34	56.88	42.66	27	7,129.5	518.35	10,366.0	753.67
3	88.02	48.90	127.98	71.10	28	7,667.6	537.90	11,149.0	782.10
4	156.48	68.46	227.52	99.54	29	8,225.0	557.46	11,988.0	810.54
5	244.50	88.02	355.50	127.98	30	8,802.0	577.01	12,797.0	839.00
6	352.08	107.58	511.92	156.42	31	9,398.5	596.59	13,665.0	867.41
7	479.22	127.14	696.78	184.86	32	10,015.0	616.14	14,561.0	895.86
8	625.92	146.70	910.08	213.30	33	10,650.0	635.70	15,486.0	924.30
9	792.18	166.26	1,151.82	241.74	34	11,306.0	655.26	16,439.0	952.70
10	978.00	185.82	1,422.00	270.18	35	11,980.0	674.81	17,420.0	981.19
11	1,183.38	205.38	1,720.62	298.62	36	12,675.0	694.39	18,429.0	1,009.60
12	1,408.32	224.94	2,047.68	327.06	37	13,389.0	713.94	19,467.0	1,038.10
13	1,652.82	244.50	2,403.18	355.50	38	14,123.0	733.50	20,533.0	1,066.50
14	1,916.88	264.06	2,787.12	383.94	39	14,875.0	753.07	21,629.0	1,095.00
15	2,200.50	283.62	3,199.50	412.38	40	15,648.0	772.63	22,752.0	1,123.40
16	2,503.68	303.18	3,640.32	440.82	41	16,440.0	792.20	23,904.0	1,151.80
17	2,826.42	322.74	4,109.56	469.26	42	17,252.0	811.74	25,084.0	1,180.30
18	3,168.72	342.30	4,607.28	497.70	43	18,083.0	830.73	26,293.0	1,208.70
19	3,530.58	361.86	5,133.42	526.14	44	18,934.0	850.86	27,530.0	1,237.20
20	3,912.00	381.42	5,688.00	554.58	45	19,804.0	870.41	28,793.0	1,265.60
21	4,313.00	400.98	6,271.00	583.26	46	20,695.0	889.99	30,090.0	1,294.00
22	4,733.50	420.54	6,882.50	611.46	47	21,605.0	909.54	31,412.0	1,322.30
23	5,173.70	440.10	7,522.50	639.90	48	22,533.0	929.10	32,763.0	1,350.90
24	5,633.30	459.67	8,190.70	668.35	49	23,482.0	948.66	34,143.0	1,379.40
25	6,112.60	479.22	8,887.50	696.79	50	24,450.0	968.21	35,550.0	1,407.90

Horsepowers for Coal Conveyors (Coal Included).

Speed, 100 ft. per minute. Conveyors, 100 ft. long. Standard steel troughs.

Size of Chain.	Size of Flights In.	Horizontal. 12 In. Between Flights.	Horizontal. 18 In. Between Flights.	Inclined. 12 In. Between Flights.	Size of Chain.	Size of Flights. In.	Horizontal. 16 In. Between Flights.	Horizontal. 24 In. Between Flights.	Inclined. 16 In. Between Flights.
½ in. or ⅝ in. Dodge.	4 × 10	2½	2	3	¾ in. Dodge.	5 × 15	4	3½	4½
	4 × 12	3	2½	3½		6 × 18	5	4	5½
	5 × 12	3½	3	4		8 × 18	7	5	8
	5 × 15	4½	3½	5½		8 × 20	8	6	10
	6 × 18	5½	4½	6½		8 × 24	9½	7	11½
						10 × 24	12½	8	14

Weights and Capacities of Standard Steel Buckets.

Chain.	Size of Bucket. In.	Weight of Bucket. Lb.	Capacity of Bucket. Lb.	Capacity of Elevator. 100′ per Min. Lb. per Min.	Capacity of Elevator. 100′ per Min. Net Tons per Hr.	Number of Drawing.
5/8 In. Dodge.	12 × 9 × 11¾	18½	11	1,100	33.0	5,357
	14 × 9 × 11¾	22½	12½	1,250	37.5	5,357
	18 × 9 × 11¾	27	16½	1,650	49.5	5,357
	24 × 9 × 11¾	36	22	2,200	66.0	5,357
3/4 In. Dodge.	12 × 10 × 16¼	20	19	1,380	41.4	5,357
	18 × 10 × 16¼	29	28½	2,072	62.2	5,357
	24 × 10 × 16¼	38	38	2,760	82.8	5,357
	30 × 10 × 16¼	46½	47½	3,450	103.5	5,357
	18 × 12 × 16¼	31	33	2,400	72.0	5,357
	24 × 12 × 16¼	40	44	3,200	96.0	5,357
	30 × 12 × 16¼	48	55	4,000	120.0	5,357

Buckets taken ¾ full. Buckets continuous. 1 lb. of coal = 34 cu. in.

Elevating Capacities of Malleable Iron Buckets.

Table gives tons (2,000 lb.) of pea coal per hour at 100 ft. per minute.

Buckets.		Capacities.		Distance Between Buckets in In.								
Size. In.	Wt. Lb.	Cu. In.	Lb.	8	10	12	14	16	18	20	22	24
2¾ × 4	0.75	15	0.48	2.16	1.73	1.44	1.23	1.08				
3½ × 5	1.50	31	0.97	4.36	3.49	2.91	2.49	2.18	1.94			
4 × 6	2.00	51	1.57	7.06	5.65	4.71	4.04	3.53	3.14	2.83		
4½ × 7	2.56	75	2.33	10.38	8.39	6.99	5.99	5.19	4.66	4.19	3.81	
5 × 8	3.56	102	3.15		11.34	9.45	8.10	7.09	6.30	5.67	5.15	4.72
6 × 10	5.47	185	5.73			17.19	14.73	12.88	11.46	10.31	9.38	8.59
7 × 12	8.97	287	8.90				22.88	20.02	17.80	16.02	14.56	13.35
7 × 14	11.41	295	9.14					20.56	18.28	16.45	14.95	13.71
10 × 18												

Weight of 1 cu. ft. of pea coal = 53.5 lb. 32.3 cu. in., or .0187 cu. ft. = 1 lb.

Conveying Capacities of Flights at 100 Ft. Per Minute.

(Tons of Pea Coal per Hour.)

Size of Flight. In.	Horizontal.				Inclined.		
					10°	20°	30°
	Every 16 In.	Every 18 In.	Every 24 In.	Lb. Coal per Flight.	Every 24 In.	Every 24 In.	Every 24 In.
4 × 10	33.75	30	22.5	15	18.0	14.25	10.5
4 × 12	42.75	38	28.5	19	24.0	18.00	13.5
5 × 12	51.75	46	34.5	23	28.5	22.50	16.5
5 × 15	69.75	62	46.5	31	40.5	31.50	22.5
6 × 18		80	60.0	40	49.5	40.50	31.5
8 × 18		120	90.0	60	72.0	57.00	48.0
8 × 20			105.0	70	84.0	66.50	56.0
8 × 24			135.0	90	120.0	96.00	72.0
10 × 24			172.5	115	150.0	120.00	90.0

NOTE.—These ratings are for continuous feed. 2,000 lb. = 1 ton.

Horsepower for Bucket Elevators.

$$\text{H. P.} = N \times \frac{H\omega}{d}.$$

N = number taken from table;
H = height of elevator in feet;
ω = weight of material in one bucket;
d = distance apart of buckets, in inches.

Revolutions per Minute.	Diameter of Head-Wheels.						Revolutions per Minute.
	22 In.	24 In.	26 In.	28 In.	30 In.	32 In.	
10	.064	.070	.075	.080	.087	.093	10
12	.077	.083	.090	.097	.104	.111	12
14	.089	.096	.106	.114	.121	.130	14
16	.102	.111	.121	.130	.140	.148	16
18	.115	.125	.136	.146	.157	.167	18
20	.128	.139	.151	.162	.174	.186	20
22	.140	.153	.166	.179	.191	.204	22
24	.153	.167	.181	.195	.209	.223	24
26	.166	.181	.196	.211	.226	.242	26
28	.179	.195	.211	.227	.244	.260	28
30	.191	.209	.226	.244	.261	.279	30
32	.204	.223	.241	.260	.278	.297	32
34	.217	.237	.256	.276	.296	.316	34
36	.230	.251	.271	.292	.313	.334	36
38	.242	.265	.287	.309	.331	.353	38
40	.255	.279	.302	.325	.348	.372	40

COST OF UNLOADING COAL.

Coal is generally unloaded from railroad cars into the hold of a vessel by some form of unloader, which usually raises the car bodily and dumps it directly into the hold of the vessel. In this way the cost of unloading has been reduced to a very small figure, and the speed of unloading greatly increased. The cost of unloading is given by the makers of the Brown hoist as varying from 2½ cents per ton up to 4¼ cents per ton; deducting in each case 2 cents for trimming the coal in the vessel, the actual cost of loading varies from ½ cent to 2½ cents per ton, depending on the conditions. Along the Lakes it is customary to pay a premium of ½ cent per ton to all connected with the loading, for all coal loaded in excess of 2,500 tons per day and 1,800 tons per night. The Brown hoist has a guaranteed capacity of at least 300 tons per hour, but this has been greatly exceeded in practice. The McMyler end dump has a record of 4.65 tons per minute, and the McMyler side dump of 8.41 tons per minute. These figures apply to the lake cities of the U. S.

The C. W. Hunt Co., West New Brighton, N. Y., gives the following figures for handling coal along the Atlantic seaboard: The cost of shoveling coal by hand in the hold of the vessel into ordinary iron buckets is about 6 to 7 cents per ton of 2,000 lb.; the cost for iron ore, phosphate rock, or sand, about 10% less. The cost of shoveling coal and hoisting it out of vessel to the wharf with an ordinary hoist with manila rope is 12 to 13 cents per ton, so that the hoisting costs about the same as the shoveling. The cost for both shoveling and hoisting with a steam engine is 10 to 11 cents per ton. The cost when using a steam shovel or grab bucket for taking up coal out of the vessel varies greatly in different classes of vessels, but usually runs from about 1½ to 5 cents per ton, averaging about 3 cents. After the coal is hoisted, it can be carried into storage with an automatic railway or other efficient plant, at a cost of about 1 to 1½ cents per ton. For great distances, a cable railway or a conveyor can be used, which handles the material about as cheaply as for short distances, but the cost of plant is greatly increased.

In unloading anthracite from cars on a trestle into pockets or on the ground, the loss on all sizes is 2 to 3% when the coal is not resized; when it is resized the loss is 8½ to 9%.

The cost of stocking and unloading anthracite by the Dodge system is given by Mr. Piez, "Mines and Minerals," June, 1898, page 488, as follows:

Year.	Engine Service, Stocking and Lifting, per Ton. Cents.	Office Expense, per Ton. Cents.	Steam, Wages and Fuel, per Ton. Cents.	Labor, Dumping and Lifting, per Ton. Cents.	Repairs, per Ton. Cents.	Supplies, per Ton. Cents.	Total, per Ton. Cents.
1895	.87	.29	.97	2.67	.78	.25	5.83
1896	.78	.30	.82	2.19	.90	.27	5.26
1897	.69	.32	.62	1.88	.97	.16	4.64

BRIQUETING.

Machines Employed.—Fuel, fuel dust, and other products may be briqueted by a number of different styles of machines, but all these may be divided into two classes, briquet and eggette machines. The eggette machines have a pair of rollers, the faces of which are provided with semispherical or semi-ovoid openings. The material that is fed between these rolls crowds into the openings of the two rolls, thus forming small spheres. The material is mixed with a suitable bond before being fed to the rolls, and the eggettes are received on any suitable form of traveling belt or chute and removed for drying or storage. This style of machine has not been used to any great extent in this country. The briqueting machines all act more or less on the principle of the brick machine, having some kind of a die or mold into which the material is crowded. The material is either pressed as it is being fed into the mold or subsequently by some form of plunger. For some materials, common brick machines, such as are used in the manufacture of building brick, are employed, while in others special forms are necessary.

Briqueting of Fuel.—Fuel briquets have not come into general use in the United States for two reasons: (1) on account of the great amount of cheap fuel available, which has prevented the utilization of culm, coal dust, etc.; and (2) on account of the lack of or high price of suitable bonding material. This latter condition is now being removed by the introduction of by-product coke ovens, from which supplies of coal tar can be obtained. Aside from peat and certain kinds of brown coal, and possibly some caking coals, it is necessary to employ a bond in the making of any fuel briquets. This is especially true in the case of anthracite coal The present tendency is to employ no inorganic bonding materials, as they increase the ash. The material to be briqueted should be as clean and free from dirt or slate as possible, and the particles should be of practically uniform size, the most satisfactory product being from coal crushed to about $\frac{1}{8}$ in. cube size. The coal must be thoroughly mixed with bonding material and then subjected to a heavy pressure. One advantage claimed for briquets is that they can be made of such a form as to occupy less space than the original fuel. The French navy has found it possible to store 10% more briquets than coal in a given space, and also that the loss by breakage and pulverization is very much less. Under favorable conditions, fuel can be briqueted for 20 cents per ton, and the following are some of the advantages claimed for these briquets: They are sound throughout and will not decrepitate while burning, thus reducing the loss by fine material working through the grates. The bond, if properly selected, renders the briquets practically waterproof, so that they are not injured if kept in storage, do not evolve combustible gases, nor ignite from spontaneous combustion. There is no fine material mixed with the briquets, and hence a more uniform fire can be maintained with them.

Briqueting of Flue Dust.—Flue dust from iron blast furnaces has been successfully briqueted in a number of instances. One firm employs a common brick machine, making bricks $2\frac{1}{2}$ in. $\times$ $4\frac{1}{2}$ in. $\times$ 9 in. With this machine, they mix the flue dust with 3% of lime and 3% of cement, the lime acting as a flux in the furnace. These machines work with comparatively light pressure. When regular briqueting machines, producing round bricks and

employing high pressures are employed, no cement need be used, the flue dust being mixed with 4% to 6% lime. The flue dust is first carefully screened from hard lumps and then mixed warm with milk of lime in a mixer, after which it is put through the press, and the briquets are then placed in drying ovens and subjected to heat from the gases of a boiler or furnace plant, the temperature not to exceed 300° F. For moderate sized briquets, about 6 hours' drying is sufficient. Just before the briquets are quite dry, they are loaded into barrels and taken direct to the blast furnace, with as little handling as possible. The results have been very satisfactory compared with the ore replaced. The flue dust itself frequently contains 30% to 40% metallic iron and more or less carbonaceous matter. It is also stated that at a large furnace plant the cost of making and handling should not exceed $1 per ton.

Another firm, figuring on a basis of 130 tons per 24 hours, and using 3% lime in the solution, gave the following figures:

4 tons lime, $3.00 per ton	$12.00	
2 machine tenders (day and night), 12 hours, at $2.50	5.00	
2 laborers (day and night), 12 hours, at $1.75	3.50	
Oil and waste	2.00	
Wear on machinery	1.50	
Interest on cost of plant	1.00	$25.00

This is less than 20 cents per ton. This estimate does not take into consideration the cost of power, which would be about 35 H. P., nor does it take into consideration hauling of material to plant and removing of briquets.

Cubic Feet Occupied by 2,000 Pounds of Various Coals.

(*Link-Belt Engineering Co., Philadelphia, Pa.*)

Varieties.	Broken.	Egg.	Stove.	Chestnut.	Pea.
Lackawanna, anthracite	37.10	36.65	34.90	34.35	37.25
Garfield red ash, anthracite	37.30	36.95	36.35	36.35	37.50
Lykens Valley, anthracite	37.55	37.25	37.55	37.25	38.50
Shamokin, anthracite	38.05	37.70	37.25	37.25	38.50
Plymouth red ash, anthracite	34.90	34.85	34.75	34.70	36.90
Wilkes-Barre, anthracite	34.95	34.35	33.75	34.00	36.90
Lehigh, anthracite	33.30	33.80	33.55	32.55	33.05
Lorberry, anthracite	34.65	34.20	33.80	33.55	35.20
Scranton, anthracite	35.35	35.20	34.60	33.30	34.95
Pittston, anthracite	35.45	34.95	34.35	33.70	35.50

Cumberland, bituminous	36.65	Pocahontas, bituminous	34.00
Clearfield, bituminous	33.55	American cannel, bituminous	41.50
New River, bituminous	40.15	English cannel, bituminous	42.30

TREATMENT OF INJURED PERSONS.

The dangers to be feared in case of wounds, are: *shock or collapse, loss of blood*, and *unnecessary suffering in the moving of the patient.*

In shock, the injured person lies pale, faint, and cold, sometimes insensible, with feeble pulse and superficial breathing. The cause of death in case of a shock is arrest of heart action, produced by the suspension of the functions of the brain and spinal cord. In treatment, the two most important parts are: (1) the position of the injured person; (2) the application of external warmth.

The injured person should at once be placed in a recumbent position, his head resting on a plane lower than that of his trunk, legs, and feet. He should be well wrapped up and protected from the chilling influences of external air. When there is danger of immediate death, stimulants should be given; in all other conditions of shock, stimulants are injurious.

Loss of Blood.—In case of loss of blood, two conditions present themselves: (1) The bleeding is arrested spontaneously or otherwise, but the injured person presents all the symptoms of loss of blood; (2) the injured person is actually bleeding, and he is, or is not, suffering from loss of blood.

In the first condition, life is threatened by anemia of brain and spinal cord, and all the efforts of treatment are to direct the flow of whatever

quantity of blood may still remain in the body to the vital centers in the brain and spinal cord. This is most efficiently done by placing the injured person in a recumbent position, with his head resting on a plane somewhat

FIG. 1.

FIG. 2.

lower than that of his trunk and legs. In graver cases, constricting bands should be applied to both arms, as near the shoulders as possible, and to both thighs, as near the abdomen as possible. This last maneuver directs the entire quantity of blood in the body to the suffering centers, the centers of life itself. Stimulants may be sparingly administered.

If there is bleeding, do not try to stop it by binding up the wound. *The current of blood to the part must be checked.* To do this, find the artery, by its beating; lay a firm and even compress or pad (made of cloth or rags rolled up, or a round stone or piece of wood well wrapped) *over the artery* (Fig. 1). Tie a handkerchief around the limb and compress; put a bit of stick through the handkerchief and twist the latter up until it is *just tight enough to stop the bleeding;* then put one end of the stick under the handkerchief, to prevent untwisting, as in Fig. 2.

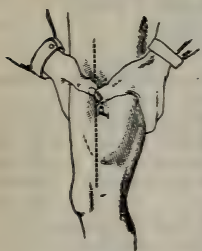


FIG. 3.

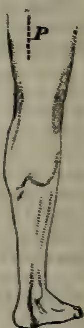


FIG. 4.

The artery in the thigh runs along the inner side of the muscle in front near the bone, as shown by dotted line in Fig. 3. A little above the knee it passes to the back of the bone. In injuries at or above the knee, apply the compress higher up. on the inner side of the thigh, at the point *P*, Fig. 3, with the knot on the outside of the thigh.

When the leg is injured below the knee, apply the compress at the back of the thigh, just above the knee, at *P*, Fig. 4, and the knot in front, as in Figs. 1 and 2.

The artery in the arm runs down the inner side of the large muscle in front, quite close to the bone, as shown by dotted line; low down it is further forwards, towards the bend of the elbow. It is most easily compressed a little above the middle, at *P*, Fig. 5. Care should be taken to examine the limb from time to time, and to lessen the compression if it becomes cold or purple; tighten up the handkerchief again if the bleeding begins afresh.

To Transport a Wounded Person Comfortably. Make a soft and even bed for the injured part, of straw, folded blankets, quilts, or

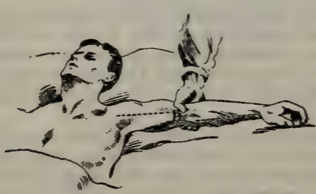


FIG. 5

FIG. 6.

pillows, laid on a board with side pieces of board nailed on, when this can be done. If possible, let the patient be laid on a door, shutter, settee, or some firm support, properly covered. Have sufficient force to lift him steadily, and let those that bear him *not* keep step.

Should any important arteries be opened, apply the handkerchief, as recommended. Secure the vessel by a surgeon's dressing forceps, or by a

hook, then have a silk ligature put around the vessel, and tighten. Should the bleeding be from arterial vessels of small size, apply *persulphate of iron*, either in tincture or in powder, by wetting a piece of lint or sponge with the solution; then, after bleeding ceases, apply a compress against the parts, to sustain them during the application of the persulphate of iron, and to prevent further bleeding, should it occur. The persulphate of iron should be kept in or about all working places.

Bleeding From Scalp Wounds.—A pad or compress is placed immediately before the ear, over the region marked by a dotted line, Fig. 6. The compress is firmly secured by a handkerchief. If this does not arrest bleeding, a similar compress on the opposite side should be applied. Should the bleeding issue from a wound of the posterior or back part of the head, a compress should be placed behind the ear, over the region marked by the dotted line, Fig. 6, and firmly secured by a handkerchief or bandage.

TREATMENT OF PERSONS OVERCOME BY GAS.

Miners are exposed to asphyxia when the circulation of the air is not sufficiently active, when the mine exhales a quantity of deleterious gas, when they imprudently penetrate into old and abandoned workings, and when there is an explosion.

The symptoms of asphyxia are sudden cessation of the respiration, of the pulsations of the heart, and of the action of the senses; the countenance is swollen and marked with reddish spots, the eyes are protruded, the features are distorted, and the face is often livid, etc.

The best and first remedy to employ, and in which the greatest confidence ought to be placed, is the renewal of the air necessary for respiration. Proceed as follows:

1. Promptly withdraw the asphyxiated person from the deleterious place and expose him to pure air.

2. Loosen the clothes round the neck and chest, and dash cold water in the face and on the chest.

3. Attempts should be made to irritate the mucous membrane with the feathered end of a quill, which should be gently moved in the nostrils of the insensible person, or to stimulate it with a bottle of volatile alkali placed under the nose.

4. Keep up the warmth of the body, and apply mustard plasters over the heart and around the ankles.

5. If these means fail to produce respiration, Doctor Sylvester's method of producing artificial respiration should be tried as follows:

Place the patient on the back on a flat surface, inclined a little upwards from the feet; raise and support the head and shoulders on a small firm cushion or folded article of dress placed under the shoulder blades. Draw forwards the patient's tongue and keep it projecting beyond the lips; an elastic band over the tongue and under the chin will answer this purpose, or a piece of string or tape may be tied around them, or by raising the lower jaw the teeth may be made to retain the tongue in that position. Remove all tight clothing from about the neck and chest, especially the suspenders. Then standing at the patient's head, grasp the arms just above the elbows, and draw the arms gently and steadily upwards above the head, and keep them stretched upwards for 2 seconds (by this means air is drawn into the lungs). Then turn down the patient's arms and press them gently and firmly for 2 seconds against the sides of the chest (by this means air is pressed out of the lungs). Repeat these measures alternately, deliberately, and perseveringly about 15 times in a minute, until a spontaneous effort to respire is perceived, immediately upon which cease to imitate the movements of breathing, and proceed to induce circulation and warmth.

6. To promote warmth and circulation, rub the limbs upwards with firm, grasping pressure and energy, using handkerchiefs, flannels, etc. Apply hot flannels, bottles of hot water, heated bricks, etc. to the pit of the stomach, the arm pits, between the thighs, and to the soles of the feet.

7. On the restoration of life, a teaspoonful of warm water should be given, and then, if the power of swallowing has returned, small quantities of wine, warm brandy and water, or coffee should be administered.

8. These remedies should be promptly applied, and as death does not certainly appear for a long time, they ought only to be discontinued when it is clearly confirmed. Absence of the pulsation of the heart is not a sure sign of death, neither is the want of respiration.

COAL DEALERS' COMPUTING TABLE, FOR ASCERTAINING THE PRICE OF ANY NUMBER OF POUNDS, AT A GIVEN PRICE PER TON OF 2,000 POUNDS.

Lb.	$0.75	$1.00	$1.25	$1.50	$1.75	$2.00	$2.25	$2.50	$2.75
10	.01	.01	.01	.01	.01	.01	.01	.01	.01
20	.01	.01	.01	.02	.02	.02	.02	.03	.03
30	.01	.02	.02	.02	.03	.03	.03	.04	.04
40	.02	.02	.03	.03	.04	.04	.04	.05	.06
50	.02	.02	.03	.04	.04	.05	.06	.06	.07
60	.02	.03	.04	.05	.05	.06	.07	.08	.08
70	.03	.03	.04	.05	.06	.07	.08	.09	.10
80	.03	.04	.05	.06	.07	.08	.09	.10	.11
90	.03	.04	.06	.07	.08	.09	.10	.11	.12
100	.04	.05	.06	.08	.09	.10	.11	.13	.14
200	.08	.10	.13	.15	.17	.20	.23	.25	.28
300	.11	.15	.19	.23	.26	.30	.34	.38	.41
400	.15	.20	.25	.30	.35	.40	.45	.50	.55
500	.19	.25	.31	.38	.44	.50	.56	.63	.69
600	.23	.30	.37	.45	.53	.60	.68	.75	.83
700	.26	.35	.44	.53	.61	.70	.77	.88	.96
800	.30	.40	.50	.60	.70	.80	.90	1.00	1.10
900	.34	.45	.56	.68	.79	.90	1.01	1.13	1.24
1,000	.38	.50	.63	.75	.88	1.00	1.13	1.25	1.38
1,100	.41	.55	.69	.83	.96	1.10	1.24	1.38	1.51
1,200	.45	.60	.75	.90	1.05	1.20	1.35	1.50	1.65
1,300	.49	.65	.81	.98	1.14	1.30	1.46	1.63	1.79
1,400	.52	.70	.88	1.05	1.22	1.40	1.58	1.75	1.93
1,500	.56	.75	.94	1.13	1.31	1.50	1.69	1.88	2.06
1,600	.60	.80	1.00	1.20	1.40	1.60	1.80	2.00	2.20
1,700	.64	.85	1.06	1.28	1.49	1.70	1.91	2.13	2.34
1,800	.68	.90	1.13	1.35	1.58	1.80	2.03	2.25	2.48
1,900	.71	.95	1.19	1.43	1.66	1.90	2.14	2.38	2.61

Lb.	$3.00	$3.25	$3.50	$3.75	$4.00	$4.25	$4.50	$4.75	$5.00
10	.02	.02	.02	.02	.02	.02	.03	.03	.03
20	.03	.03	.04	.04	.04	.05	.05	.05	.05
30	.05	.05	.05	.06	.06	.07	.07	.07	.08
40	.06	.07	.07	.08	.08	.09	.09	.10	.10
50	.08	.08	.09	.09	.10	.11	.12	.12	.13
60	.09	.10	.11	.11	.12	.13	.14	.15	.15
70	.11	.11	.12	.13	.14	.15	.16	.17	.18
80	.12	.13	.14	.15	.16	.17	.18	.19	.20
90	.14	.15	.16	.17	.18	.19	.20	.22	.23
100	.15	.16	.18	.19	.20	.22	.23	.24	.25
200	.30	.33	.35	.38	.40	.43	.45	.48	.50
300	.45	.49	.53	.56	.60	.64	.68	.72	.75
400	.60	.65	.70	.75	.80	.85	.90	.95	1.00
500	.75	.81	.88	.94	1.00	1.07	1.13	1.19	1.25
600	.90	.98	1.05	1.13	1.20	1.28	1.35	1.43	1.50
700	1.05	1.14	1.23	1.31	1.40	1.49	1.58	1.67	1.75
800	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
900	1.35	1.46	1.58	1.69	1.80	1.92	2.03	2.14	2.25
1,000	1.50	1.63	1.75	1.88	2.00	2.13	2.25	2.38	2.50
1,100	1.65	1.79	1.93	2.06	2.20	2.34	2.48	2.62	2.75
1,200	1.80	1.95	2.10	2.25	2.40	2.55	2.70	2.85	3.00
1,300	1.95	2.11	2.28	2.44	2.60	2.77	2.93	3.09	3.25
1,400	2.10	2.28	2.45	2.63	2.80	2.98	3.15	3.33	3.50
1,500	2.25	2.44	2.63	2.81	3.00	3.19	3.38	3.57	3.75
1,600	2.40	2.60	2.80	3.00	3.20	3.40	3.60	3.80	4.00
1,700	2.55	2.76	2.98	3.19	3.40	3.62	3.83	4.04	4.25
1,800	2.70	2.93	3.15	3.38	3.60	3.83	4.05	4.28	4.50
1,900	2.85	3.09	3.33	3.56	3.80	4.04	4.28	4.52	4.75

TABLE OF NATURAL SINES, COSINES, TANGENTS, AND COTANGENTS.

EXPLANATION.

Given an angle, to find its sine, cosine, tangent, and cotangent:

EXAMPLE.—Find the sine, cosine, tangent, and cotangent of 37° 24′.

Look in the table of *natural sines* along the tops of the pages, and find 37°. Glancing *down* the left-hand column marked (′), until 24 is found, find opposite this 24 in the column marked *sine* and headed 37°, the number .60738; then .60738 = sin 37° 24′. Similarly, find in the column marked *cosine* and headed 37°, the number .79441, which corresponds to cos 37° 24′. So, also, find in the column marked *tangent* and headed 37°, and opposite 24′, the number .76456; and in the column marked *cotangent* and headed 37°, and opposite 24′, the number 1.30795.

In most of the tables published, the angles run only from 0° to 45° at the heads of the columns; to find an angle greater than 45°, *look at the bottom of the page and glance upwards, using the extreme right-hand column to find minutes*, which begin with 0 at the bottom and run upwards, 1, 2, 3, etc. up to 60.

EXAMPLE.—Find the sine of 77° 43′.

Look along the bottom of the tables until the column marked *sine* and marked 77° is found. Glancing up the column of minutes on the *right* until 43′ is found, find opposite 43′ in the column marked *sine* at the bottom and marked 77°, the number .97711; this is the sine of 77° 43′. Similarly, the cosine, tangent, and cotangent may be found.

To find the sine, cosine, tangent, or cotangent of an angle whose exact value is not given in the table:

Rule.—*Find in the table the sine, cosine, tangent, or cotangent corresponding to the degrees and minutes of the angle.*

For the seconds, find the difference of the values of the sine, cosine, tangent, or cotangent taken from the table between which the seconds of the angle fall; multiply this difference by a fraction whose numerator is the number of seconds in the given angle and whose denominator is 60.

If sine or tangent, add this correction to the value first found; if cosine or cotangent, subtract the correction.

EXAMPLE.—Find the sine, cosine, tangent, and cotangent of 56° 43′ 17″.

Sin 56° 43′ = .83597. Sin 56° 44′ = .83613. Since 56° 43′ 17″ is greater than 56° 43′ and less than 56° 44′, the value of the sine of the angle lies between .83597 and .83613; the difference equals .83613 − .83597 = .00016; multiplying this by the fraction $\frac{17}{60}$, $.00016 \times \frac{17}{60} = .00005$, nearly, which is to be *added* to .83597, the value first found, or .83597 + .00005 = .83602. Hence, sin 56° 43′ 17″ = .83602.

Cos 56° 43′ = .54878; cos 56° 44′ = .54854; the difference equals .54878 − .54854 = .00024, and $.00024 \times \frac{17}{60} = .00007$, nearly. Now, since the *cosine* is desired, we must *subtract* this correction from cos 56° 43′, or .54878; subtracting, .54878 − .00007 = .54871. Hence, cos 56° 43′ 17″ = .54871.

Given the sine, cosine, tangent, or cotangent, to find the angle corresponding:

EXAMPLE.—The sine of an angle is .47486; what is the angle?

Consulting the table of natural sines, glance down the columns marked *sine* until .47486 is found, opposite 21′ in the left-hand column and under the column headed 28°. Therefore, the angle whose sine = .47486 is 28° 21′, or sin 28° 21′ = .47486.

To find the angle corresponding to a given sine, cosine, tangent, or cotangent whose exact value is not contained in the table:

Rule.—*Find the difference of the two numbers in the table between which the given sine, cosine, tangent, or cotangent falls, and use the number of parts in this difference as the denominator of a fraction.*

Find the difference between the number belonging to the smaller angle and the given sine, cosine, tangent, or cotangent, and use the number of parts in the difference just found as the numerator of the fraction mentioned above. Multiply this fraction by 60, and the result will be the number of seconds to be added to the smaller angle.

EXAMPLE.—Find the angle whose sine equals .57698.

Looking in the table of natural sines, in the column marked *sine*, it is found between .57691 = sin 35° 14′ and .57715 = 35° 15′. The difference between them is .57715 — .57691 = .00024, or 24 parts. The difference between the sine of the smaller angle, or sin 35° 14′ = .57691, and the given sine, or .57698, is .57698 — .57691 = .00007, or 7 parts.

Then, $\frac{7}{24} \times 60 = 17.5''$, and the angle = 35° 14′ 17.5″, or sin 35° 14′ 17.5″ = .57698.

The cosecant of an angle is equal to the reciprocal of its sine, and the secant is equal to the reciprocal of its cosine. Hence, to multiply a quantity by the cosecant, divide it by the sine; or, to divide it by the cosecant, multiply it by the sine. Similarly, to multiply a quantity by the secant of an angle, divide it by the cosine; or, to divide it by the secant, multiply it by the cosine.

′	0°		1°		2°		3°		4°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.00000	1.	.01745	.99985	.03490	.99939	.05234	.99863	.06976	.99756	60
1	.00029	1.	.01774	.99984	.03519	.99938	.05263	.99861	.07005	.99754	59
2	.00058	1.	.01803	.99984	.03548	.99937	.05292	.99860	.07034	.99752	58
3	.00087	1.	.01832	.99983	.03577	.99936	.05321	.99858	.07063	.99750	57
4	.00116	1.	.01862	.99983	.03606	.99935	.05350	.99857	.07092	.99748	56
5	.00145	1.	.01891	.99982	.03635	.99934	.05379	.99855	.07121	.99746	55
6	.00175	1.	.01920	.99982	.03664	.99933	.05408	.99854	.07150	.99744	54
7	.00204	1.	.01949	.99981	.03693	.99932	.05437	.99852	.07179	.99742	53
8	.00233	1.	.01978	.99980	.03723	.99931	.05466	.99851	.07208	.99740	52
9	.00262	1.	.02007	.99980	.03752	.99930	.05495	.99849	.07237	.99738	51
10	.00291	1.	.02036	.99979	.03781	.99929	.05524	.99847	.07266	.99736	50
11	.00320	.99999	.02065	.99979	.03810	.99927	.05553	.99846	.07295	.99734	49
12	.00349	.99999	.02094	.99978	.03839	.99926	.05582	.99844	.07324	.99731	48
13	.00378	.99999	.02123	.99977	.03868	.99925	.05611	.99842	.07353	.99729	47
14	.00407	.99999	.02152	.99977	.03897	.99924	.05640	.99841	.07382	.99727	46
15	.00436	.99999	.02181	.99976	.03926	.99923	.05669	.99839	.07411	.99725	45
16	.00465	.99999	.02211	.99976	.03955	.99922	.05698	.99838	.07440	.99723	44
17	.00495	.99999	.02240	.99975	.03984	.99921	.05727	.99836	.07469	.99721	43
18	.00524	.99999	.02269	.99974	.04013	.99919	.05756	.99834	.07498	.99719	42
19	.00553	.99998	.02298	.99974	.04042	.99918	.05785	.99833	.07527	.99716	41
20	.00582	.99998	.02327	.99973	.04071	.99917	.05814	.99831	.07556	.99714	40
21	.00611	.99998	.02356	.99972	.04100	.99916	.05844	.99829	.07585	.99712	39
22	.00640	.99998	.02385	.99972	.04129	.99915	.05873	.99827	.07614	.99710	38
23	.00669	.99998	.02414	.99971	.04159	.99913	.05902	.99826	.07643	.99708	37
24	.00698	.99998	.02443	.99970	.04188	.99912	.05931	.99824	.07672	.99705	36
25	.00727	.99997	.02472	.99969	.04217	.99911	.05960	.99822	.07701	.99703	35
26	.00756	.99997	.02501	.99969	.04246	.99910	.05989	.99821	.07730	.99701	34
27	.00785	.99997	.02530	.99968	.04275	.99909	.06018	.99819	.07759	.99699	33
28	.00814	.99997	.02560	.99967	.04304	.99907	.06047	.99817	.07788	.99696	32
29	.00844	.99996	.02589	.99966	.04333	.99906	.06076	.99815	.07817	.99694	31
30	.00873	.99996	.02618	.99966	.04362	.99905	.06105	.99813	.07846	.99692	30
31	.00902	.99996	.02647	.99965	.04391	.99904	.06134	.99812	.07875	.99689	29
32	.00931	.99996	.02676	.99964	.04420	.99902	.06163	.99810	.07904	.99687	28
33	.00960	.99995	.02705	.99963	.04449	.99901	.06192	.99808	.07933	.99685	27
34	.00989	.99995	.02734	.99963	.04478	.99900	.06221	.99806	.07962	.99683	26
35	.01018	.99995	.02763	.99962	.04507	.99898	.06250	.99804	.07991	.99680	25
36	.01047	.99995	.02792	.99961	.04536	.99897	.06279	.99803	.08020	.99678	24
37	.01076	.99994	.02821	.99960	.04565	.99896	.06308	.99801	.08049	.99676	23
38	.01105	.99994	.02850	.99959	.04594	.99894	.06337	.99799	.08078	.99673	22
39	.01134	.99994	.02879	.99959	.04623	.99893	.06366	.99797	.08107	.99671	21
40	.01164	.99993	.02908	.99958	.04653	.99892	.06395	.99795	.08136	.99668	20
41	.01193	.99993	.02938	.99957	.04682	.99890	.06424	.99793	.08165	.99666	19
42	.01222	.99993	.02967	.99956	.04711	.99889	.06453	.99792	.08194	.99664	18
43	.01251	.99992	.02996	.99955	.04740	.99888	.06482	.99790	.08223	.99661	17
44	.01280	.99992	.03025	.99954	.04769	.99886	.06511	.99788	.08252	.99659	16
45	.01309	.99991	.03054	.99953	.04798	.99885	.06540	.99786	.08281	.99657	15
46	.01338	.99991	.03083	.99952	.04827	.99883	.06569	.99784	.08310	.99654	14
47	.01367	.99991	.03112	.99952	.04856	.99882	.06598	.99782	.08339	.99652	13
48	.01396	.99990	.03141	.99951	.04885	.99881	.06627	.99780	.08368	.99649	12
49	.01425	.99990	.03170	.99950	.04914	.99879	.06656	.99778	.08397	.99647	11
50	.01454	.99989	.03199	.99949	.04943	.99878	.06685	.99776	.08426	.99644	10
51	.01483	.99989	.03228	.99948	.04972	.99876	.06714	.99774	.08455	.99642	9
52	.01513	.99989	.03257	.99947	.05001	.99875	.06743	.99772	.08484	.99639	8
53	.01542	.99988	.03286	.99946	.05030	.99873	.06773	.99770	.08513	.99637	7
54	.01571	.99988	.03316	.99945	.05059	.99872	.06802	.99768	.08542	.99635	6
55	.01600	.99987	.03345	.99944	.05088	.99870	.06831	.99766	.08571	.99632	5
56	.01629	.99987	.03374	.99943	.05117	.99869	.06860	.99764	.08600	.99630	4
57	.01658	.99986	.03403	.99942	.05146	.99867	.06889	.99762	.08629	.99627	3
58	.01687	.99986	.03432	.99941	.05175	.99866	.06918	.99760	.08658	.99625	2
59	.01716	.99985	.03461	.99940	.05205	.99864	.06947	.99758	.08687	.99622	1
60	.01745	.99985	.03490	.99939	.05234	.99863	.06976	.99756	.08716	.99619	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	89°		88°		87°		86°		85°		

′	5°		6°		7°		8°		9°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.08716	.99619	.10453	.99452	.12187	.99255	.13917	.99027	.15643	.98769	60
1	.08745	.99617	.10482	.99449	.12216	.99251	.13946	.99023	.15672	.98764	59
2	.08774	.99614	.10511	.99446	.12245	.99248	.13975	.99019	.15701	.98760	58
3	.08803	.99612	.10540	.99443	.12274	.99244	.14004	.99015	.15730	.98755	57
4	.08831	.99609	.10569	.99440	.12302	.99240	.14033	.99011	.15758	.98751	56
5	.08860	.99607	.10597	.99437	.12331	.99237	.14061	.99006	.15787	.98746	55
6	.08889	.99604	.10626	.99434	.12360	.99233	.14090	.99002	.15816	.98741	54
7	.08918	.99602	.10655	.99431	.12389	.99230	.14119	.98998	.15845	.98737	53
8	.08947	.99599	.10684	.99428	.12418	.99226	.14148	.98994	.15873	.98732	52
9	.08976	.99596	.10713	.99424	.12447	.99222	.14177	.98990	.15902	.98728	51
10	.09005	.99594	.10742	.99421	.12476	.99219	.14205	.98986	.15931	.98723	50
11	.09034	.99591	.10771	.99418	.12504	.99215	.14234	.98982	.15959	.98718	49
12	.09063	.99588	.10800	.99415	.12533	.99211	.14263	.98978	.15988	.98714	48
13	.09092	.99586	.10829	.99412	.12562	.99208	.14292	.98973	.16017	.98709	47
14	.09121	.99583	.10858	.99409	.12591	.99204	.14320	.98969	.16046	.98704	46
15	.09150	.99580	.10887	.99406	.12620	.99200	.14349	.98965	.16074	.98700	45
16	.09179	.99578	.10916	.99402	.12649	.99197	.14378	.98961	.16103	.98695	44
17	.09208	.99575	.10945	.99399	.12678	.99193	.14407	.98957	.16132	.98690	43
18	.09237	.99572	.10973	.99396	.12706	.99189	.14436	.98953	.16160	.98686	42
19	.09266	.99570	.11002	.99393	.12735	.99186	.14464	.98948	.16189	.98681	41
20	.09295	.99567	.11031	.99390	.12764	.99182	.14493	.98944	.16218	.98676	40
21	.09324	.99564	.11060	.99386	.12793	.99178	.14522	.98940	.16246	.98671	39
22	.09353	.99562	.11089	.99383	.12822	.99175	.14551	.98936	.16275	.98667	38
23	.09382	.99559	.11118	.99380	.12851	.99171	.14580	.98931	.16304	.98662	37
24	.09411	.99556	.11147	.99377	.12880	.99167	.14608	.98927	.16333	.98657	36
25	.09440	.99553	.11176	.99374	.12908	.99163	.14637	.98923	.16361	.98652	35
26	.09469	.99551	.11205	.99370	.12937	.99160	.14666	.98919	.16390	.98648	34
27	.09498	.99548	.11234	.99367	.12966	.99156	.14695	.98914	.16419	.98643	33
28	.09527	.99545	.11263	.99364	.12995	.99152	.14723	.98910	.16447	.98638	32
29	.09556	.99542	.11291	.99360	.13024	.99148	.14752	.98906	.16476	.98633	31
30	.09585	.99540	.11320	.99357	.13053	.99144	.14781	.98902	.16505	.98629	30
31	.09614	.99537	.11349	.99354	.13081	.99141	.14810	.98897	.16533	.98624	29
32	.09642	.99534	.11378	.99351	.13110	.99137	.14838	.98893	.16562	.98619	28
33	.09671	.99531	.11407	.99347	.13139	.99133	.14867	.98889	.16591	.98614	27
34	.09700	.99528	.11436	.99344	.13168	.99129	.14896	.98884	.16620	.98609	26
35	.09729	.99526	.11465	.99341	.13197	.99125	.14925	.98880	.16648	.98604	25
36	.09758	.99523	.11494	.99337	.13226	.99122	.14954	.98876	.16677	.98600	24
37	.09787	.99520	.11523	.99334	.13254	.99118	.14982	.98871	.16706	.98595	23
38	.09816	.99517	.11552	.99331	.13283	.99114	.15011	.98867	.16734	.98590	22
39	.09845	.99514	.11580	.99327	.13312	.99110	.15040	.98863	.16763	.98585	21
40	.09874	.99511	.11609	.99324	.13341	.99106	.15069	.98858	.16792	.98580	20
41	.09903	.99508	.11638	.99320	.13370	.99102	.15097	.98854	.16820	.98575	19
42	.09932	.99506	.11667	.99317	.13399	.99098	.15126	.98849	.16849	.98570	18
43	.09961	.99503	.11696	.99314	.13427	.99094	.15155	.98845	.16878	.98565	17
44	.09990	.99500	.11725	.99310	.13456	.99091	.15184	.98841	.16906	.98561	16
45	.10019	.99497	.11754	.99307	.13485	.99087	.15212	.98836	.16935	.98556	15
46	.10048	.99494	.11783	.99303	.13514	.99083	.15241	.98832	.16964	.98551	14
47	.10077	.99491	.11812	.99300	.13543	.99079	.15270	.98827	.16992	.98546	13
48	.10106	.99488	.11840	.99297	.13572	.99075	.15299	.98823	.17021	.98541	12
49	.10135	.99485	.11869	.99293	.13600	.99071	.15327	.98818	.17050	.98536	11
50	.10164	.99482	.11898	.99290	.13629	.99067	.15356	.98814	.17078	.98531	10
51	.10192	.99479	.11927	.99286	.13658	.99063	.15385	.98809	.17107	.98526	9
52	.10221	.99476	.11956	.99283	.13687	.99059	.15414	.98805	.17136	.98521	8
53	.10250	.99473	.11985	.99279	.13716	.99055	.15442	.98800	.17164	.98516	7
54	.10279	.99470	.12014	.99276	.13744	.99051	.15471	.98796	.17193	.98511	6
55	.10308	.99467	.12043	.99272	.13773	.99047	.15500	.98791	.17222	.98506	5
56	.10337	.99464	.12071	.99269	.13802	.99043	.15529	.98787	.17250	.98501	4
57	.10366	.99461	.12100	.99265	.13831	.99039	.15557	.98782	.17279	.98496	3
58	.10395	.99458	.12129	.99262	.13860	.99035	.15586	.98778	.17308	.98491	2
59	.10424	.99455	.12158	.99258	.13889	.99031	.15615	.98773	.17336	.98486	1
60	.10453	.99452	.12187	.99255	.13917	.99027	.15643	.98769	.17365	.98481	0
	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	
′	84°		83°		82°		81°		80°		′

′	10° Sine	10° Cosine	11° Sine	11° Cosine	12° Sine	12° Cosine	13° Sine	13° Cosine	14° Sine	14° Cosine	′
0	.17365	.98481	.19081	.98163	.20791	.97815	.22495	.97437	.24192	.97030	60
1	.17393	.98476	.19109	.98157	.20820	.97809	.22523	.97430	.24220	.97023	59
2	.17422	.98471	.19138	.98152	.20848	.97803	.22552	.97424	.24249	.97015	58
3	.17451	.98466	.19167	.98146	.20877	.97797	.22580	.97417	.24277	.97008	57
4	.17479	.98461	.19195	.98140	.20905	.97791	.22608	.97411	.24305	.97001	56
5	.17508	.98455	.19224	.98135	.20933	.97784	.22637	.97404	.24333	.96994	55
6	.17537	.98450	.19252	.98129	.20962	.97778	.22665	.97398	.24362	.96987	54
7	.17565	.98445	.19281	.98124	.20990	.97772	.22693	.97391	.24390	.96980	53
8	.17594	.98440	.19309	.98118	.21019	.97766	.22722	.97384	.24418	.96973	52
9	.17623	.98435	.19338	.98112	.21047	.97760	.22750	.97378	.24446	.96966	51
10	.17651	.98430	.19366	.98107	.21076	.97754	.22778	.97371	.24474	.96959	50
11	.17680	.98425	.19395	.98101	.21104	.97748	.22807	.97365	.24503	.96952	49
12	.17708	.98420	.19423	.98096	.21132	.97742	.22835	.97358	.24531	.96945	48
13	.17737	.98414	.19452	.98090	.21161	.97735	.22863	.97351	.24559	.96937	47
14	.17766	.98409	.19481	.98084	.21189	.97729	.22892	.97345	.24587	.96930	46
15	.17794	.98404	.19509	.98079	.21218	.97723	.22920	.97338	.24615	.96923	45
16	.17823	.98399	.19538	.98073	.21246	.97717	.22948	.97331	.24644	.96916	44
17	.17852	.98394	.19566	.98067	.21275	.97711	.22977	.97325	.24672	.96909	43
18	.17880	.98389	.19595	.98061	.21303	.97705	.23005	.97318	.24700	.96902	42
19	.17909	.98383	.19623	.98056	.21331	.97698	.23033	.97311	.24728	.96894	41
20	.17937	.98378	.19652	.98050	.21360	.97692	.23062	.97304	.24756	.96887	40
21	.17966	.98373	.19680	.98044	.21388	.97686	.23090	.97298	.24784	.96880	39
22	.17995	.98368	.19709	.98039	.21417	.97680	.23118	.97291	.24813	.96873	38
23	.18023	.98362	.19737	.98033	.21445	.97673	.23146	.97284	.24841	.96866	37
24	.18052	.98357	.19766	.98027	.21474	.97667	.23175	.97278	.24869	.96858	36
25	.18081	.98352	.19794	.98021	.21502	.97661	.23203	.97271	.24897	.96851	35
26	.18109	.98347	.19823	.98016	.21530	.97655	.23231	.97264	.24925	.96844	34
27	.18138	.98341	.19851	.98010	.21559	.97648	.23260	.97257	.24954	.96837	33
28	.18166	.98336	.19880	.98004	.21587	.97642	.23288	.97251	.24982	.96829	32
29	.18195	.98331	.19908	.97998	.21616	.97636	.23316	.97244	.25010	.96822	31
30	.18224	.98325	.19937	.97992	.21644	.97630	.23345	.97237	.25038	.96815	30
31	.18252	.98320	.19965	.97987	.21672	.97623	.23373	.97230	.25066	.96807	29
32	.18281	.98315	.19994	.97981	.21701	.97617	.23401	.97223	.25094	.96800	28
33	.18309	.98310	.20022	.97975	.21729	.97611	.23429	.97217	.25122	.96793	27
34	.18338	.98304	.20051	.97969	.21758	.97604	.23458	.97210	.25151	.96786	26
35	.18367	.98299	.20079	.97963	.21786	.97598	.23486	.97203	.25179	.96778	25
36	.18395	.98294	.20108	.97958	.21814	.97592	.23514	.97196	.25207	.96771	24
37	.18424	.98288	.20136	.97952	.21843	.97585	.23542	.97189	.25235	.96764	23
38	.18452	.98283	.20165	.97946	.21871	.97579	.23571	.97182	.25263	.96756	22
39	.18481	.98277	.20193	.97940	.21899	.97573	.23599	.97176	.25291	.96749	21
40	.18509	.98272	.20222	.97934	.21928	.97566	.23627	.97169	.25320	.96742	20
41	.18538	.98267	.20250	.97928	.21956	.97560	.23656	.97162	.25348	.96734	19
42	.18567	.98261	.20279	.97922	.21985	.97553	.23684	.97155	.25376	.96727	18
43	.18595	.98256	.20307	.97916	.22013	.97547	.23712	.97148	.25404	.96719	17
44	.18624	.98250	.20336	.97910	.22041	.97541	.23740	.97141	.25432	.96712	16
45	.18652	.98245	.20364	.97905	.22070	.97534	.23769	.97134	.25460	.96705	15
46	.18681	.98240	.20393	.97899	.22098	.97528	.23797	.97127	.25488	.96697	14
47	.18710	.98234	.20421	.97893	.22126	.97521	.23825	.97120	.25516	.96690	13
48	.18738	.98229	.20450	.97887	.22155	.97515	.23853	.97113	.25545	.96682	12
49	.18767	.98223	.20478	.97881	.22183	.97508	.23882	.97106	.25573	.96675	11
50	.18795	.98218	.20507	.97875	.22212	.97502	.23910	.97100	.25601	.96667	10
51	.18824	.98212	.20535	.97869	.22240	.97496	.23938	.97093	.25629	.96660	9
52	.18852	.98207	.20563	.97863	.22268	.97489	.23966	.97086	.25657	.96653	8
53	.18881	.98201	.20592	.97857	.22297	.97483	.23995	.97079	.25685	.96645	7
54	.18910	.98196	.20620	.97851	.22325	.97476	.24023	.97072	.25713	.96638	6
55	.18938	.98190	.20649	.97845	.22353	.97470	.24051	.97065	.25741	.96630	5
56	.18967	.98185	.20677	.97839	.22382	.97463	.24079	.97058	.25769	.96623	4
57	.18995	.98179	.20706	.97833	.22410	.97457	.24108	.97051	.25798	.96615	3
58	.19024	.98174	.20734	.97827	.22438	.97450	.24136	.97044	.25826	.96608	2
59	.19052	.98168	.20763	.97821	.22467	.97444	.24164	.97037	.25854	.96600	1
60	.19081	.98163	.20791	.97815	.22495	.97437	.24192	.97030	.25882	.96593	0
′	79° Cosine	79° Sine	78° Cosine	78° Sine	77° Cosine	77° Sine	76° Cosine	76° Sine	75° Cosine	75° Sine	′

′	15°		16°		17°		18°		19°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.25882	.96593	.27564	.96126	.29237	.95630	.30902	.95106	.32557	.94552	60
1	.25910	.96585	.27592	.96118	.29265	.95622	.30929	.95097	.32584	.94542	59
2	.25938	.96578	.27620	.96110	.29293	.95613	.30957	.95088	.32612	.94533	58
3	.25966	.96570	.27648	.96102	.29321	.95605	.30985	.95079	.32639	.94523	57
4	.25994	.96562	.27676	.96094	.29348	.95596	.31012	.95070	.32667	.94514	56
5	.26022	.96555	.27704	.96086	.29376	.95588	.31040	.95061	.32694	.94504	55
6	.26050	.96547	.27731	.96078	.29404	.95579	.31068	.95052	.32722	.94495	54
7	.26079	.96540	.27759	.96070	.29432	.95571	.31095	.95043	.32749	.94485	53
8	.26107	.96532	.27787	.96062	.29460	.95562	.31123	.95033	.32777	.94476	52
9	.26135	.96524	.27815	.96054	.29487	.95554	.31151	.95024	.32804	.94466	51
10	.26163	.96517	.27843	.96046	.29515	.95545	.31178	.95015	.32832	.94457	50
11	.26191	.96509	.27871	.96037	.29543	.95536	.31206	.95006	.32859	.94447	49
12	.26219	.96502	.27899	.96029	.29571	.95528	.31233	.94997	.32887	.94438	48
13	.26247	.96494	.27927	.96021	.29599	.95519	.31261	.94988	.32914	.94428	47
14	.26275	.96486	.27955	.96013	.29626	.95511	.31289	.94979	.32942	.94418	46
15	.26303	.96479	.27983	.96005	.29654	.95502	.31316	.94970	.32969	.94409	45
16	.26331	.96471	.28011	.95997	.29682	.95493	.31344	.94961	.32997	.94399	44
17	.26359	.96463	.28039	.95989	.29710	.95485	.31372	.94952	.33024	.94390	43
18	.26387	.96456	.28067	.95981	.29737	.95476	.31399	.94943	.33051	.94380	42
19	.26415	.96448	.28095	.95972	.29765	.95467	.31427	.94933	.33079	.94370	41
20	.26443	.96440	.28123	.95964	.29793	.95459	.31454	.94924	.33106	.94361	40
21	.26471	.96433	.28150	.95956	.29821	.95450	.31482	.94915	.33134	.94351	39
22	.26500	.96425	.28178	.95948	.29849	.95441	.31510	.94906	.33161	.94342	38
23	.26528	.96417	.28206	.95940	.29876	.95433	.31537	.94897	.33189	.94332	37
24	.26556	.96410	.28234	.95931	.29904	.95424	.31565	.94888	.33216	.94322	36
25	.26584	.96402	.28262	.95923	.29932	.95415	.31593	.94878	.33244	.94313	35
26	.26612	.96394	.28290	.95915	.29960	.95407	.31620	.94869	.33271	.94303	34
27	.26640	.96386	.28318	.95907	.29987	.95398	.31648	.94860	.33298	.94293	33
28	.26668	.96379	.28346	.95898	.30015	.95389	.31675	.94851	.33326	.94284	32
29	.26696	.96371	.28374	.95890	.30043	.95380	.31703	.94842	.33353	.94274	31
30	.26724	.96363	28402	.95882	.30071	.95372	.31730	.94832	.33381	.94264	30
31	.26752	.96355	.28429	.95874	.30098	.95363	.31758	.94823	.33408	.94254	29
32	.26780	.96347	.28457	.95865	.30126	.95354	.31786	.94814	.33436	.94245	28
33	.26808	.96340	.28485	.95857	.30154	.95345	.31813	.94805	.33463	.94235	27
34	.26836	.96332	.28513	.95849	.30182	.95337	.31841	.94795	.33490	.94225	26
35	.26864	.96324	.28541	.95841	.30209	.95328	.31868	.94786	.33518	.94215	25
36	.26892	.96316	.28569	.95832	.30237	.95319	.31896	.94777	.33545	.94206	24
37	.26920	.96308	.28597	.95824	.30265	.95310	.31923	.94768	.33573	.94196	23
38	.26948	.96301	.28625	.95816	.30292	.95301	.31951	.94758	.33600	.94186	22
39	.26976	.96293	.28652	.95807	.30320	.95293	.31979	.94749	.33627	.94176	21
40	.27004	.96285	.28680	.95799	.30348	.95284	.32006	.94740	.33655	.94167	20
41	.27032	.96277	.28708	.95791	.30376	.95275	.32034	.94730	.33682	.94157	19
42	.27060	.96269	.28736	.95782	.30403	.95266	.32061	.94721	.33710	.94147	18
43	.27088	.96261	.28764	.95774	.30431	.95257	.32089	.94712	.33737	.94137	17
44	.27116	.96253	.28792	.95766	.30459	.95248	.32116	.94702	.33764	.94127	16
45	.27144	.96246	.28820	.95757	.30486	.95240	.32144	.94693	.33792	.94118	15
46	.27172	.96238	.28847	.95749	.30514	.95231	.32171	.94684	.33819	.94108	14
47	.27200	.96230	.28875	.95740	.30542	.95222	.32199	.94674	.33846	.94098	13
48	.27228	.96222	.28903	.95732	.30570	.95213	.32227	.94665	.33874	.94088	12
49	.27256	.96214	.28931	.95724	.30597	.95204	.32254	.94656	.33901	.94078	11
50	.27284	.96206	.28959	.95715	.30625	.95195	.32282	.94646	.33929	.94068	10
51	.27312	.96198	.28987	.95707	.30653	.95186	.32309	.94637	.33956	.94058	9
52	.27340	.96190	.29015	.95698	.30680	.95177	.32337	.94627	.33983	.94049	8
53	.27368	.96182	.29042	.95690	.30708	.95168	.32364	.94618	.34011	.94039	7
54	.27396	.96174	.29070	.95681	.30736	.95159	.32392	.94609	.34038	.94029	6
55	.27424	.96166	.29098	.95673	.30763	.95150	.32419	.94599	.34065	.94019	5
56	.27452	.96158	.29126	.95664	.30791	.95142	.32447	.94590	.34093	.94009	4
57	.27480	.96150	.29154	.95656	.30819	.95133	.32474	.94580	.34120	.93999	3
58	.27508	.96142	.29182	.95647	.30846	.95124	.32502	.94571	.34147	.93989	2
59	.27536	.96134	.29209	.95639	.30874	.95115	.32529	.94561	.34175	.93979	1
60	.27564	.96126	.29237	.95630	.30902	.95106	.32557	.94552	.34202	.93969	0
	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	
′	74°		73°		72°		71°		70°		′

′	20° Sine	20° Cosine	21° Sine	21° Cosine	22° Sine	22° Cosine	23° Sine	23° Cosine	24° Sine	24° Cosine	′
0	.34202	.93969	.35837	.93358	.37461	.92718	.39073	.92050	.40674	.91355	60
1	.34229	.93959	.35864	.93348	.37488	.92707	.39100	.92039	.40700	.91343	59
2	.34257	.93949	.35891	.93337	.37515	.92697	.39127	.92028	.40727	.91331	58
3	.34284	.93939	.35918	.93327	.37542	.92686	.39153	.92016	.40753	.91319	57
4	.34311	.93929	.35945	.93316	.37569	.92675	.39180	.92005	.40780	.91307	56
5	.34339	.93919	.35973	.93306	.37595	.92664	.39207	.91994	.40806	.91295	55
6	.34366	.93909	.36000	.93295	.37622	.92653	.39234	.91982	.40833	.91283	54
7	.34393	.93899	.36027	.93285	.37649	.92642	.39260	.91971	.40860	.91272	53
8	.34421	.93889	.36054	.93274	.37676	.92631	.39287	.91959	.40886	.91260	52
9	.34448	.93879	.36081	.93264	.37703	.92620	.39314	.91948	.40913	.91248	51
10	.34475	.93869	.36108	.93253	.37730	.92609	.39341	.91936	.40939	.91236	50
11	.34503	.93859	.36135	.93243	.37757	.92598	.39367	.91925	.40966	.91224	49
12	.34530	.93849	.36162	.93232	.37784	.92587	.39394	.91914	.40992	.91212	48
13	.34557	.93839	.36190	.93222	.37811	.92576	.39421	.91902	.41019	.91200	47
14	.34584	.93829	.36217	.93211	.37838	.92565	.39448	.91891	.41045	.91188	46
15	.34612	.93819	.36244	.93201	.37865	.92554	.39474	.91879	.41072	.91176	45
16	.34639	.93809	.36271	.93190	.37892	.92543	.39501	.91868	.41098	.91164	44
17	.34666	.93799	.36298	.93180	.37919	.92532	.39528	.91856	.41125	.91152	43
18	.34694	.93789	.36325	.93169	.37946	.92521	.39555	.91845	.41151	.91140	42
19	.34721	.93779	.36352	.93159	.37973	.92510	.39581	.91833	.41178	.91128	41
20	.34748	.93769	.36379	.93148	.37999	.92499	.39608	.91822	.41204	.91116	40
21	.34775	.93759	.36406	.93137	.38026	.92488	.39635	.91810	.41231	.91104	39
22	.34803	.93748	.36434	.93127	.38053	.92477	.39661	.91799	.41257	.91092	38
23	.34830	.93738	.36461	.93116	.38080	.92466	.39688	.91787	.41284	.91080	37
24	.34857	.93728	.36488	.93106	.38107	.92455	.39715	.91775	.41310	.91068	36
25	.34884	.93718	.36515	.93095	.38134	.92444	.39741	.91764	.41337	.91056	35
26	.34912	.93708	.36542	.93084	.38161	.92432	.39768	.91752	.41363	.91044	34
27	.34939	.93698	.36569	.93074	.38188	.92421	.39795	.91741	.41390	.91032	33
28	.34966	.93688	.36596	.93063	.38215	.92410	.39822	.91729	.41416	.91020	32
29	.34993	.93677	.36623	.93052	.38241	.92399	.39848	.91718	.41443	.91008	31
30	.35021	.93667	.36650	.93042	.38268	.92388	.39875	.91706	.41469	.90996	30
31	.35048	.93657	.36677	.93031	.38295	.92377	.39902	.91694	.41496	.90984	29
32	.35075	.93647	.36704	.93020	.38322	.92366	.39928	.91683	.41522	.90972	28
33	.35102	.93637	.36731	.93010	.38349	.92355	.39955	.91671	.41549	.90960	27
34	.35130	.93626	.36758	.92999	.38376	.92343	.39982	.91660	.41575	.90948	26
35	.35157	.93616	.36785	.92988	.38403	.92332	.40008	.91648	.41602	.90936	25
36	.35184	.93606	.36812	.92978	.38430	.92321	.40035	.91636	.41628	.90924	24
37	.35211	.93596	.36839	.92967	.38456	.92310	.40062	.91625	.41655	.90911	23
38	.35239	.93585	.36867	.92956	.38483	.92299	.40088	.91613	.41681	.90899	22
39	.35266	.93575	.36894	.92945	.38510	.92287	.40115	.91601	.41707	.90887	21
40	.35293	.93565	.36921	.92935	.38537	.92276	.40141	.91590	.41734	.90875	20
41	.35320	.93555	.36948	.92924	.38564	.92265	.40168	.91578	.41760	.90863	19
42	.35347	.93544	.36975	.92913	.38591	.92254	.40195	.91566	.41787	.90851	18
43	.35375	.93534	.37002	.92902	.38617	.92243	.40221	.91555	.41813	.90839	17
44	.35402	.93524	.37029	.92892	.38644	.92231	.40248	.91543	.41840	.90826	16
45	.35429	.93514	.37056	.92881	.38671	.92220	.40275	.91531	.41866	.90814	15
46	.35456	.93502	.37083	.92870	.38698	.92209	.40301	.91519	.41892	.90802	14
47	.35484	.93493	.37110	.92859	.38725	.92198	.40328	.91508	.41919	.90790	13
48	.35511	.93483	.37137	.92849	.38752	.92186	.40355	.91496	.41945	.90778	12
49	.35538	.93472	.37164	.92838	.38778	.92175	.40381	.91484	.41972	.90766	11
50	.35565	.93462	.37191	.92827	.38805	.92164	.40408	.91472	.41998	.90753	10
51	.35592	.93452	.37218	.92816	.38832	.92152	.40434	.91461	.42024	.90741	9
52	.35619	.93441	.37245	.92805	.38859	.92141	.40461	.91449	.42051	.90729	8
53	.35647	.93431	.37272	.92794	.38886	.92130	.40488	.91437	.42077	.90717	7
54	.35674	.93420	.37299	.92784	.38912	.92119	.40514	.91425	.42104	.90704	6
55	.35701	.93410	.37326	.92773	.38939	.92107	.40541	.91414	.42130	.90692	5
56	.35728	.93400	.37353	.92762	.38966	.92096	.40567	.91402	.42156	.90680	4
57	.35755	.93389	.37380	.92751	.38993	.92085	.40594	.91390	.42183	.90668	3
58	.35782	.93379	.37407	.92740	.39020	.92073	.40621	.91378	.42209	.90655	2
59	.35810	.93368	.37434	.92729	.39046	.92062	.40647	.91366	.42235	.90643	1
60	.35837	.93358	.37461	.92718	.39073	.92050	.40674	.91355	.42262	.90631	0
′	69° Cosine	69° Sine	68° Cosine	68° Sine	67° Cosine	67° Sine	66° Cosine	66° Sine	65° Cosine	65° Sine	′

′	25°		26°		27°		28°		29°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.42262	.90631	.43837	.89879	.45399	.89101	.46947	.88295	.48481	.87462	60
1	.42288	.90618	.43863	.89867	.45425	.89087	.46973	.88281	.48506	.87448	59
2	.42315	.90606	.43889	.89854	.45451	.89074	.46999	.88267	.48532	.87434	58
3	.42341	.90594	.43916	.89841	.45477	.89061	.47024	.88254	.48557	.87420	57
4	.42367	.90582	.43942	.89828	.45503	.89048	.47050	.88240	.48583	.87406	56
5	.42394	.90569	.43968	.89816	.45529	.89035	.47076	.88226	.48608	.87391	55
6	.42420	.90557	.43994	.89803	.45554	.89021	.47101	.88213	.48634	.87377	54
7	.42446	.90545	.44020	.89790	.45580	.89008	.47127	.88199	.48659	.87363	53
8	.42473	.90532	.44046	.89777	.45606	.88995	.47153	.88185	.48684	.87349	52
9	.42499	.90520	.44072	.89764	.45632	.88981	.47178	.88172	.48710	.87335	51
10	.42525	.90507	.44098	.89752	.45658	.88968	.47204	.88158	.48735	.87321	50
11	.42552	.90495	.44124	.89739	.45684	.88955	.47229	.88144	.48761	.87306	49
12	.42578	.90483	.44151	.89726	.45710	.88942	.47255	.88130	.48786	.87292	48
13	.42604	.90470	.44177	.89713	.45736	.88928	.47281	.88117	.48811	.87278	47
14	.42631	.90458	.44203	.89700	.45762	.88915	.47306	.88103	.48837	.87264	46
15	.42657	.90446	.44229	.89687	.45787	.88902	.47332	.88089	.48862	.87250	45
16	.42683	.90433	.44255	.89674	.45813	.88888	.47358	.88075	.48888	.87235	44
17	.42709	.90421	.44281	.89662	.45839	.88875	.47383	.88062	.48913	.87221	43
18	.42736	.90408	.44307	.89649	.45865	.88862	.47409	.88048	.48938	.87207	42
19	.42762	.90396	.44333	.89636	.45891	.88848	.47434	.88034	.48964	.87193	41
20	.42788	.90383	.44359	.89623	.45917	.88835	.47460	.88020	.48989	.87178	40
21	.42815	.90371	.44385	.89610	.45942	.88822	.47486	.88006	.49014	.87164	39
22	.42841	.90358	.44411	.89597	.45968	.88808	.47511	.87993	.49040	.87150	38
23	.42867	.90346	.44437	.89584	.45994	.88795	.47537	.87979	.49065	.87136	37
24	.42894	.90334	.44464	.89571	.46020	.88782	.47562	.87965	.49090	.87121	36
25	.42920	.90321	.44490	.89558	.46046	.88768	.47588	.87951	.49116	.87107	35
26	.42946	.90309	.44516	.89545	.46072	.88755	.47614	.87937	.49141	.87093	34
27	.42972	.90296	.44542	.89532	.46097	.88741	.47639	.87923	.49166	.87079	33
28	.42999	.90284	.44568	.89519	.46123	.88728	.47665	.87909	.49192	.87064	32
29	.43025	.90271	.44594	.89506	.46149	.88715	.47690	.87896	.49217	.87050	31
30	.43051	.90259	.44620	.89493	.46175	.88701	.47716	.87882	.49242	.87036	30
31	.43077	.90246	.44646	.89480	.46201	.88688	.47741	.87868	.49268	.87021	29
32	.43104	.90233	.44672	.89467	.46226	.88674	.47767	.87854	.49293	.87007	28
33	.43130	.90221	.44698	.89454	.46252	.88661	.47793	.87840	.49318	.86993	27
34	.43156	.90208	.44724	.89441	.46278	.88647	.47818	.87826	.49344	.86978	26
35	.43182	.90196	.44750	.89428	.46304	.88634	.47844	.87812	.49369	.86964	25
36	.43209	.90183	.44776	.89415	.46330	.88620	.47869	.87798	.49394	.86949	24
37	.43235	.90171	.44802	.89402	.46355	.88607	.47895	.87784	.49419	.86935	23
38	.43261	.90158	.44828	.89389	.46381	.88593	.47920	.87770	.49445	.86921	22
39	.43287	.90146	.44854	.89376	.46407	.88580	.47946	.87756	.49470	.86906	21
40	.43313	.90133	.44880	.89363	.46433	.88566	.47971	.87743	.49495	.86892	20
41	.43340	.90120	.44906	.89350	.46458	.88553	.47997	.87729	.49521	.86878	19
42	.43366	.90108	.44932	.89337	.46484	.88539	.48022	.87715	.49546	.86863	18
43	.43392	.90095	.44958	.89324	.46510	.88526	.48048	.87701	.49571	.86849	17
44	.43418	.90082	.44984	.89311	.46536	.88512	.48073	.87687	.49596	.86834	16
45	.43445	.90070	.45010	.89298	.46561	.88499	.48099	.87673	.49622	.86820	15
46	.43471	.90057	.45036	.89285	.46587	.88485	.48124	.87659	.49647	.86805	14
47	.43497	.90045	.45062	.89272	.46613	.88472	.48150	.87645	.49672	.86791	13
48	.43523	.90032	.45088	.89259	.46639	.88458	.48175	.87631	.49697	.86777	12
49	.43549	.90019	.45114	.89245	.46664	.88445	.48201	.87617	.49723	.86762	11
50	.43575	.90007	.45140	.89232	.46690	.88431	.48226	.87603	.49748	.86748	10
51	.43602	.89994	.45166	.89219	.46716	.88417	.48252	.87589	.49773	.86733	9
52	.43628	.89981	.45192	.89206	.46742	.88404	.48277	.87575	.49798	.86719	8
53	.43654	.89968	.45218	.89193	.46767	.88390	.48303	.87561	.49824	.86704	7
54	.43680	.89956	.45243	.89180	.46793	.88377	.48328	.87546	.49849	.86690	6
55	.43706	.89943	.45269	.89167	.46819	.88363	.48354	.87532	.49874	.86675	5
56	.43733	.89930	.45295	.89153	.46844	.88349	.48379	.87518	.49899	.86661	4
57	.43759	.89918	.45321	.89140	.46870	.88336	.48405	.87504	.49924	.86646	3
58	.43785	.89905	.45347	.89127	.46896	.88322	.48430	.87490	.49950	.86632	2
59	.43811	.89892	.45373	.89114	.46921	.88308	.48456	.87476	.49975	.86617	1
60	.43837	.89879	.45399	.89101	.46947	.88295	.48481	.87462	.50000	.86603	0
	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	
′	64°		63°		62°		61°		60°		′

′	30° Sine	30° Cosine	31° Sine	31° Cosine	32° Sine	32° Cosine	33° Sine	33° Cosine	34° Sine	34° Cosine	′
0	.50000	.86603	.51504	.85717	.52992	.84805	.54464	.83867	.55919	.82904	60
1	.50025	.86588	.51529	.85702	.53017	.84789	.54488	.83851	.55943	.82887	59
2	.50050	.86573	.51554	.85687	.53041	.84774	.54513	.83835	.55968	.82871	58
3	.50076	.86559	.51579	.85672	.53066	.84759	.54537	.83819	.55992	.82855	57
4	.50101	.86544	.51604	.85657	.53091	.84743	.54561	.83804	.56016	.82839	56
5	.50126	.86530	.51628	.85642	.53115	.84728	.54586	.83788	.56040	.82822	55
6	.50151	.86515	.51653	.85627	.53140	.84712	.54610	.83772	.56064	.82806	54
7	.50176	.86501	.51678	.85612	.53164	.84697	.54635	.83756	.56088	.82790	53
8	.50201	.86486	.51703	.85597	.53189	.84681	.54659	.83740	.56112	.82773	52
9	.50227	.86471	.51728	.85582	.53214	.84666	.54683	.83724	.56136	.82757	51
10	.50252	.86457	.51753	.85567	.53238	.84650	.54708	.83708	.56160	.82741	50
11	.50277	.86442	.51778	.85551	.53263	.84635	.54732	.83692	.56184	.82724	49
12	.50302	.86427	.51803	.85536	.53288	.84619	.54756	.83676	.56208	.82708	48
13	.50327	.86413	.51828	.85521	.53312	.84604	.54781	.83660	.56232	.82692	47
14	.50352	.86398	.51852	.85506	.53337	.84588	.54805	.83645	.56256	.82675	46
15	.50377	.86384	.51877	.85491	.53361	.84573	.54829	.83629	.56280	.82659	45
16	.50403	.86369	.51902	.85476	.53386	.84557	.54854	.83613	.56305	.82643	44
17	.50428	.86354	.51927	.85461	.53411	.84542	.54878	.83597	.56329	.82626	43
18	.50453	.86340	.51952	.85446	.53435	.84526	.54902	.83581	.56353	.82610	42
19	.50478	.86325	.51977	.85431	.53460	.84511	.54927	.83565	.56377	.82593	41
20	.50503	.86310	.52002	.85416	.53484	.84495	.54951	.83549	.56401	.82577	40
21	.50528	.86295	.52026	.85401	.53509	.84480	.54975	.83533	.56425	.82561	39
22	.50553	.86281	.52051	.85385	.53534	.84464	.54999	.83517	.56449	.82544	38
23	.50578	.86266	.52076	.85370	.53558	.84448	.55024	.83501	.56473	.82528	37
24	.50603	.86251	.52101	.85355	.53583	.84433	.55048	.83485	.56497	.82511	36
25	.50628	.86237	.52126	.85340	.53607	.84417	.55072	.83469	.56521	.82495	35
26	.50654	.86222	.52151	.85325	.53632	.84402	.55097	.83453	.56545	.82478	34
27	.50679	.86207	.52175	.85310	.53656	.84386	.55121	.83437	.56569	.82462	33
28	.50704	.86192	.52200	.85294	.53681	.84370	.55145	.83421	.56593	.82446	32
29	.50729	.86178	.52225	.85279	.53705	.84355	.55169	.83405	.56617	.82429	31
30	.50754	.86163	.52250	.85264	.53730	.84339	.55194	.83389	.56641	.82413	30
31	.50779	.86148	.52275	.85249	.53754	.84324	.55218	.83373	.56665	.82396	29
32	.50804	.86133	.52299	.85234	.53779	.84308	.55242	.83356	.56689	.82380	28
33	.50829	.86119	.52324	.85218	.53804	.84292	.55266	.83340	.56713	.82363	27
34	.50854	.86104	.52349	.85203	.53828	.84277	.55291	.83324	.56736	.82347	26
35	.50879	.86089	.52374	.85188	.53853	.84261	.55315	.83308	.56760	.82330	25
36	.50904	.86074	.52399	.85173	.53877	.84245	.55339	.83292	.56784	.82314	24
37	.50929	.86059	.52423	.85157	.53902	.84230	.55363	.83276	.56808	.82297	23
38	.50954	.86045	.52448	.85142	.53926	.84214	.55388	.83260	.56832	.82281	22
39	.50979	.86030	.52473	.85127	.53951	.84198	.55412	.83244	.56856	.82264	21
40	.51004	.86015	.52498	.85112	.53975	.84182	.55436	.83228	.56880	.82248	20
41	.51029	.86000	.52522	.85096	.54000	.84167	.55460	.83212	.56904	.82231	19
42	.51054	.85985	.52547	.85081	.54024	.84151	.55484	.83195	.56928	.82214	18
43	.51079	.85970	.52572	.85066	.54049	.84135	.55509	.83179	.56952	.82198	17
44	.51104	.85956	.52597	.85051	.54073	.84120	.55533	.83163	.56976	.82181	16
45	.51129	.85941	.52621	.85035	.54097	.84104	.55557	.83147	.57000	.82165	15
46	.51154	.85926	.52646	.85020	.54122	.84088	.55581	.83131	.57024	.82148	14
47	.51179	.85911	.52671	.85005	.54146	.84072	.55605	.83115	.57047	.82132	13
48	.51204	.85896	.52696	.84989	.54171	.84057	.55630	.83098	.57071	.82115	12
49	.51229	.85881	.52720	.84974	.54195	.84041	.55654	.83082	.57095	.82098	11
50	.51254	.85866	.52745	.84959	.54220	.84025	.55678	.83066	.57119	.82082	10
51	.51279	.85851	.52770	.84943	.54244	.84009	.55702	.83050	.57143	.82065	9
52	.51304	.85836	.52794	.84928	.54269	.83994	.55726	.83034	.57167	.82048	8
53	.51329	.85821	.52819	.84913	.54293	.83978	.55750	.83017	.57191	.82032	7
54	.51354	.85806	.52844	.84897	.54317	.83962	.55775	.83001	.57215	.82015	6
55	.51379	.85792	.52869	.84882	.54342	.83946	.55799	.82985	.57238	.81999	5
56	.51404	.85777	.52893	.84866	.54366	.83930	.55823	.82969	.57262	.81982	4
57	.51429	.85762	.52918	.84851	.54391	.83915	.55847	.82953	.57286	.81965	3
58	.51454	.85747	.52943	.84836	.54415	.83899	.55871	.82936	.57310	.81949	2
59	.51479	.85732	.52967	.84820	.54440	.83883	.55895	.82920	.57334	.81932	1
60	.51504	.85717	.52992	.84805	.54464	.83867	.55919	.82904	.57358	.81915	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	59°		58°		57°		56°		55°		

′	35°		36°		37°		38°		39°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.57358	.81915	.58779	.80902	.60182	.79864	.61566	.78801	.62932	.77715	60
1	.57381	.81899	.58802	.80885	.60205	.79846	.61589	.78783	.62955	.77696	59
2	.57405	.81882	.58826	.80867	.60228	.79829	.61612	.78765	.62977	.77678	58
3	.57429	.81865	.58849	.80850	.60251	.79811	.61635	.78747	.63000	.77660	57
4	.57453	.81848	.58873	.80833	.60274	.79793	.61658	.78729	.63022	.77641	56
5	.57477	.81832	.58896	.80816	.60298	.79776	.61681	.78711	.63045	.77623	55
6	.57501	.81815	.58920	.80799	.60321	.79758	.61704	.78694	.63068	.77605	54
7	.57524	.81798	.58943	.80782	.60344	.79741	.61726	.78676	.63090	.77586	53
8	.57548	.81782	.58967	.80765	.60367	.79723	.61749	.78658	.63113	.77568	52
9	.57572	.81765	.58990	.80748	.60390	.79706	.61772	.78640	.63135	.77550	51
10	.57596	.81748	.59014	.80730	.60414	.79688	.61795	.78622	.63158	.77531	50
11	.57619	.81731	.59037	.80713	.60437	.79671	.61818	.78604	.63180	.77513	49
12	.57643	.81714	.59061	.80696	.60460	.79653	.61841	.78586	.63203	.77494	48
13	.57667	.81698	.59084	.80679	.60483	.79635	.61864	.78568	.63225	.77476	47
14	.57691	.81681	.59108	.80662	.60506	.79618	.61887	.78550	.63248	.77458	46
15	.57715	.81664	.59131	.80644	.60529	.79600	.61909	.78532	.63271	.77439	45
16	.57738	.81647	.59154	.80627	.60553	.79583	.61932	.78514	.63293	.77421	44
17	.57762	.81631	.59178	.80610	.60576	.79565	.61955	.78496	.63316	.77402	43
18	.57786	.81614	.59201	.80593	.60599	.79547	.61978	.78478	.63338	.77384	42
19	.57810	.81597	.59225	.80576	.60622	.79530	.62001	.78460	.63361	.77366	41
20	.57833	.81580	.59248	.80558	.60645	.79512	.62024	.78442	.63383	.77347	40
21	.57857	.81563	.59272	.80541	.60668	.79494	.62046	.78424	.63406	.77329	39
22	.57881	.81546	.59295	.80524	.60691	.79477	.62069	.78405	.63428	.77310	38
23	.57904	.81530	.59318	.80507	.60714	.79459	.62092	.78387	.63451	.77292	37
24	.57928	.81513	.59342	.80489	.60738	.79441	.62115	.78369	.63473	.77273	36
25	.57952	.81496	.59365	.80472	.60761	.79424	.62138	.78351	.63496	.77255	35
26	.57976	.81479	.59389	.80455	.60784	.79406	.62160	.78333	.63518	.77236	34
27	.57999	.81462	.59412	.80438	.60807	.79388	.62183	.78315	.63540	.77218	33
28	.58023	.81445	.59436	.80420	.60830	.79371	.62206	.78297	.63563	.77199	32
29	.58047	.81428	.59459	.80403	.60853	.79353	.62229	.78279	.63585	.77181	31
30	.58070	.81412	.59482	.80386	.60876	.79335	.62251	.78261	.63608	.77162	30
31	.58094	.81395	.59506	.80368	.60899	.79318	.62274	.78243	.63630	.77144	29
32	.58118	.81378	.59529	.80351	.60922	.79300	.62297	.78225	.63653	.77125	28
33	.58141	.81361	.59552	.80334	.60945	.79282	.62320	.78206	.63675	.77107	27
34	.58165	.81344	.59576	.80316	.60968	.79264	.62342	.78188	.63698	.77088	26
35	.58189	.81327	.59599	.80299	.60991	.79247	.62365	.78170	.63720	.77070	25
36	.58212	.81310	.59622	.80282	.61015	.79229	.62388	.78152	.63742	.77051	24
37	.58236	.81293	.59646	.80264	.61038	.79211	.62411	.78134	.63765	.77033	23
38	.58260	.81276	.59669	.80247	.61061	.79193	.62433	.78116	.63787	.77014	22
39	.58283	.81259	.59693	.80230	.61084	.79176	.62456	.78098	.63810	.76996	21
40	.58307	.81242	.59716	.80212	.61107	.79158	.62479	.78079	.63832	.76977	20
41	.58330	.81225	.59739	.80195	.61130	.79140	.62502	.78061	.63854	.76959	19
42	.58354	.81208	.59763	.80178	.61153	.79122	.62524	.78043	.63877	.76940	18
43	.58378	.81191	.59786	.80160	.61176	.79105	.62547	.78025	.63899	.76921	17
44	.58401	.81174	.59809	.80143	.61199	.79087	.62570	.78007	.63922	.76903	16
45	.58425	.81157	.59832	.80125	.61222	.79069	.62592	.77988	.63944	.76884	15
46	.58449	.81140	.59856	.80108	.61245	.79051	.62615	.77970	.63966	.76866	14
47	.58472	.81123	.59879	.80091	.61268	.79033	.62638	.77952	.63989	.76847	13
48	.58496	.81106	.59902	.80073	.61291	.79016	.62660	.77934	.64011	.76828	12
49	.58519	.81089	.59926	.80056	.61314	.78998	.62683	.77916	.64033	.76810	11
50	.58543	.81072	.59949	.80038	.61337	.78980	.62706	.77897	.64056	.76791	10
51	.58567	.81055	.59972	.80021	.61360	.78962	.62728	.77879	.64078	.76772	9
52	.58590	.81038	.59995	.80003	.61383	.78944	.62751	.77861	.64100	.76754	8
53	.58614	.81021	.60019	.79986	.61406	.78926	.62774	.77843	.64123	.76735	7
54	.58637	.81004	.60042	.79968	.61429	.78908	.62796	.77824	.64145	.76717	6
55	.58661	.80978	.60065	.79951	.61451	.78891	.62819	.77806	.64167	.76698	5
56	.58684	.80970	.60089	.79934	.61474	.78873	.62842	.77788	.64190	.76679	4
57	.58708	.80953	.60112	.79916	.61497	.78855	.62864	.77769	.64212	.76661	3
58	.58731	.80936	.60135	.79899	.61520	.78837	.62887	.77751	.64234	.76642	2
59	.58755	.80919	.60158	.79881	.61543	.78819	.62909	.77733	.64256	.76623	1
60	.58779	.80902	.60182	.79864	.61566	.78801	.62932	.77715	.64279	.76604	0
	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	
′	54°		53°		52°		51°		50°		′

′	40°		41°		42°		43°		44°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.64279	.76604	.65606	.75471	.66913	.74314	.68200	.73135	.69466	.71934	60
1	.64301	.76586	.65628	.75452	.66935	.74295	.68221	.73116	.69487	.71914	59
2	.64323	.76567	.65650	.75433	.66956	.74276	.68242	.73096	.69508	.71894	58
3	.64346	.76548	.65672	.75414	.66978	.74256	.68264	.73076	.69529	.71873	57
4	.64368	.76530	.65694	.75395	.66999	.74237	.68285	.73056	.69549	.71853	56
5	.64390	.76511	.65716	.75375	.67021	.74217	.68306	.73036	.69570	.71833	55
6	.64412	.76492	.65738	.75356	.67043	.74198	.68327	.73016	.69591	.71813	54
7	.64435	.76473	.65759	.75337	.67064	.74178	.68349	.72996	.69612	.71792	53
8	.64457	.76455	.65781	.75318	.67086	.74159	.68370	.72976	.69633	.71772	52
9	.64479	.76436	.65803	.75299	.67107	.74139	.68391	.72957	.69654	.71752	51
10	.64501	.76417	.65825	.75280	.67129	.74120	.68412	.72937	.69675	.71732	50
11	.64524	.76398	.65847	.75261	.67151	.74100	.68434	.72917	.69696	.71711	49
12	.64546	.76380	.65869	.75241	.67172	.74080	.68455	.72897	.69717	.71691	48
13	.64568	.76361	.65891	.75222	.67194	.74061	.68476	.72877	.69737	.71671	47
14	.64590	.76342	.65913	.75203	.67215	.74041	.68497	.72857	.69758	.71650	46
15	.64612	.76323	.65935	.75184	.67237	.74022	.68518	.72837	.69779	.71630	45
16	.64635	.76304	.65956	.75165	.67258	.74002	.68539	.72817	.69800	.71610	44
17	.64657	.76286	.65978	.75146	.67280	.73983	.68561	.72797	.69821	.71590	43
18	.64679	.76267	.66000	.75126	.67301	.73963	.68582	.72777	.69842	.71569	42
19	.64701	.76248	.66022	.75107	.67323	.73944	.68603	.72757	.69862	.71549	41
20	.64723	.76229	.66044	.75088	.67344	.73924	.68624	.72737	.69883	.71529	40
21	.64746	.76210	.66066	.75069	.67366	.73904	.68645	.72717	.69904	.71508	39
22	.64768	.76192	.66088	.75050	.67387	.73885	.68666	.72697	.69925	.71488	38
23	.64790	.76173	.66109	.75030	.67409	.73865	.68688	.72677	.69946	.71468	37
24	.64812	.76154	.66131	.75011	.67430	.73846	.68709	.72657	.69966	.71447	36
25	.64834	.76135	.66153	.74992	.67452	.73826	.68730	.72637	.69987	.71427	35
26	.64856	.76116	.66175	.74973	.67473	.73806	.68751	.72617	.70008	.71407	34
27	.64878	.76097	.66197	.74953	.67495	.73787	.68772	.72597	.70029	.71386	33
28	.64901	.76078	.66218	.74934	.67516	.73767	.68793	.72577	.70049	.71366	32
29	.64923	.76059	.66240	.74915	.67538	.73747	.68814	.72557	.70070	.71345	31
30	.64945	.76041	.66262	.74896	.67559	.73728	.68835	.72537	.70091	.71325	30
31	.64967	.76022	.66284	.74876	.67580	.73708	.68857	.72517	.70112	.71305	29
32	.64989	.76003	.66306	.74857	.67602	.73688	.68878	.72497	.70132	.71284	28
33	.65011	.75984	.66327	.74838	.67623	.73669	.68899	.72477	.70153	.71264	27
34	.65033	.75965	.66349	.74818	.67645	.73649	.68920	.72457	.70174	.71243	26
35	.65055	.75946	.66371	.74799	.67666	.73629	.68941	.72437	.70195	.71223	25
36	.65077	.75927	.66393	.74780	.67688	.73610	.68962	.72417	.70215	.71203	24
37	.65100	.75908	.66414	.74760	.67709	.73590	.68983	.72397	.70236	.71182	23
38	.65122	.75889	.66436	.74741	.67730	.73570	.69004	.72377	.70257	.71162	22
39	.65144	.75870	.66458	.74722	.67752	.73551	.69025	.72357	.70277	.71141	21
40	.65166	.75851	.66480	.74703	.67773	.73531	.69046	.72337	.70298	.71121	20
41	.65188	.75832	.66501	.74683	.67795	.73511	.69067	.72317	.70319	.71100	19
42	.65210	.75813	.66523	.74664	.67816	.73491	.69088	.72297	.70339	.71080	18
43	.65232	.75794	.66545	.74644	.67837	.73472	.69109	.72277	.70360	.71059	17
44	.65254	.75775	.66566	.74625	.67859	.73452	.69130	.72257	.70381	.71039	16
45	.65276	.75756	.66588	.74606	.67880	.73432	.69151	.72236	.70401	.71019	15
46	.65298	.75738	.66610	.74586	.67901	.73413	.69172	.72216	.70422	.70998	14
47	.65320	.75719	.66632	.74567	.67923	.73393	.69193	.72196	.70443	.70978	13
48	.65342	.75700	.66653	.74548	.67944	.73373	.69214	.72176	.70463	.70957	12
49	.65364	.75680	.66675	.74528	.67965	.73353	.69235	.72156	.70484	.70937	11
50	.65386	.75661	.66697	.74509	.67987	.73333	.69256	.72136	.70505	.70916	10
51	.65408	.75642	.66718	.74489	.68008	.73314	.69277	.72116	.70525	.70896	9
52	.65430	.75623	.66740	.74470	.68029	.73294	.69298	.72095	.70546	.70875	8
53	.65452	.75604	.66762	.74451	.68051	.73274	.69319	.72075	.70567	.70855	7
54	.65474	.75585	.66783	.74431	.68072	.73254	.69340	.72055	.70587	.70834	6
55	.65496	.75566	.66805	.74412	.68093	.73234	.69361	.72035	.70608	.70813	5
56	.65518	.75547	.66827	.74392	.68115	.73215	.69382	.72015	.70628	.70793	4
57	.65540	.75528	.66848	.74373	.68136	.73195	.69403	.71995	.70649	.70772	3
58	.65562	.75509	.66870	.74353	.68157	.73175	.69424	.71974	.70670	.70752	2
59	.65584	.75490	.66891	.74334	.68179	.73155	.69445	.71954	.70690	.70731	1
60	.65606	.75471	.66913	.74314	.68200	.73135	.69466	.71934	.70711	.70711	0
	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	
′	49°		48°		47°		46°		45°		′

′	0°		1°		2°		3°		4°		′
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.00000	Infin.	.01746	57.2900	.03492	28.6363	.05241	19.0811	.06993	14.3007	60
1	.00029	3437.75	.01775	56.3506	.03521	28.3994	.05270	18.9755	.07022	14.2411	59
2	.00058	1718.87	.01804	55.4415	.03550	28.1664	.05299	18.8711	.07051	14.1821	58
3	.00087	1145.92	.01833	54.5613	.03579	27.9372	.05328	18.7678	.07080	14.1235	57
4	.00116	859.436	.01862	53.7086	.03609	27.7117	.05357	18.6656	.07110	14.0655	56
5	.00145	687.549	.01891	52.8821	.03638	27.4899	.05387	18.5645	.07139	14.0079	55
6	.00175	572.957	.01920	52.0807	.03667	27.2715	.05416	18.4645	.07168	13.9507	54
7	.00204	491.106	.01949	51.3032	.03696	27.0566	.05445	18.3655	.07197	13.8940	53
8	.00233	429.718	.01978	50.5485	.03725	26.8450	.05474	18.2677	.07227	13.8378	52
9	.00262	381.971	.02007	49.8157	.03754	26.6367	.05503	18.1708	.07256	13.7821	51
10	.00291	343.774	.02036	49.1039	.03783	26.4316	.05533	18.0750	.07285	13.7267	50
11	.00320	312.521	.02066	48.4121	.03812	26.2296	.05562	17.9802	.07314	13.6719	49
12	.00349	286.478	.02095	47.7395	.03842	26.0307	.05591	17.8863	.07344	13.6174	48
13	.00378	264.441	.02124	47.0853	.03871	25.8348	.05620	17.7934	.07373	13.5634	47
14	.00407	245.552	.02153	46.4489	.03900	25.6418	.05649	17.7015	.07402	13.5098	46
15	.00436	229.182	.02182	45.8294	.03929	25.4517	.05678	17.6106	.07431	13.4566	45
16	.00465	214.858	.02211	45.2261	.03958	25.2644	.05708	17.5205	.07461	13.4039	44
17	.00495	202.219	.02240	44.6386	.03987	25.0798	.05737	17.4314	.07490	13.3515	43
18	.00524	190.984	.02269	44.0661	.04016	24.8978	.05766	17.3432	.07519	13.2996	42
19	.00553	180.932	.02298	43 5081	.04046	24.7185	.05795	17.2558	.07548	13.2480	41
20	.00582	171.885	.02328	42.9641	.04075	24.5418	.05824	17.1693	.07578	13.1969	40
21	.00611	163.700	.02357	42.4335	.04104	24.3675	.05854	17.0837	.07607	13.1461	39
22	.00640	156.259	.02386	41.9158	.04133	24.1957	.05883	16.9990	.07636	13.0958	38
23	.00669	149.465	.02415	41.4106	.04162	24.0263	.05912	16.9150	.07665	13.0458	37
24	.00698	143.237	.02444	40.9174	.04191	23.8593	.05941	16.8319	.07695	12.9962	36
25	.00727	137.507	.02473	40.4358	.04220	23.6945	.05970	16.7496	.07724	12.9469	35
26	.00756	132.219	.02502	39.9655	.04250	23.5321	.05999	16.6681	.07753	12.8981	34
27	.00785	127.321	.02531	39.5059	.04279	23.3718	.06029	16.5874	.07782	12.8496	33
28	.00815	122.774	.02560	39.0568	.04308	23.2137	.06058	16.5075	.07812	12.8014	32
29	.00844	118.540	.02589	38.6177	.04337	23.0577	.06087	16.4283	.07841	12.7536	31
30	.00873	114.589	.02619	38.1885	.04366	22.9038	.06116	16.3499	.07870	12.7062	30
31	.00902	110.892	.02648	37.7686	.04395	22.7519	.06145	16.2722	.07899	12.6591	29
32	.00931	107.426	.02677	37.3579	.04424	22.6020	.06175	16.1952	.07929	12.6124	28
33	.00960	104.171	.02706	36.9560	.04454	22.4541	.06204	16.1190	.07958	12.5660	27
34	.00989	101.107	.02735	36.5627	.04483	22.3081	.06233	16.0435	.07987	12.5199	26
35	.01018	98.2179	.02764	36.1776	.04512	22.1640	.06262	15.9687	.08017	12.4742	25
36	.01047	95.4895	.02793	35.8006	.04541	22.0217	.06291	15.8945	.08046	12.4288	24
37	.01076	92.9085	.02822	35.4313	.04570	21.8813	.06321	15.8211	.08075	12.3838	23
38	.01105	90.4633	.02851	35.0695	.04599	21.7426	.06350	15.7483	.08104	12.3390	22
39	.01135	88.1436	.02881	34.7151	.04628	21.6056	.06379	15.6762	.08134	12.2946	21
40	.01164	85.9398	.02910	34.3678	.04658	21.4704	.06408	15.6048	.08163	12.2505	20
41	.01193	83.8435	.02939	34.0273	.04687	21.3369	.06437	15.5340	.08192	12.2067	19
42	.01222	81.8470	.02968	33.6935	.04716	21.2049	.06467	15.4638	.08221	12.1632	18
43	.01251	79.9434	.02997	33.3662	.04745	21.0747	.06496	15.3943	.08251	12.1201	17
44	.01280	78.1263	.03026	33.0452	.04774	20.9460	.06525	15.3254	.08280	12.0772	16
45	.01309	76.3900	.03055	32.7303	.04803	20.8188	.06554	15.2571	.08309	12.0346	15
46	.01338	74.7292	.03084	32.4213	.04833	20.6932	.06584	15.1893	.08339	11.9923	14
47	.01367	73.1390	.03114	32.1181	.04862	20 5691	.06613	15.1222	.08368	11.9504	13
48	.01396	71.6151	.03143	31.8205	.04891	20.4465	.06642	15.0557	.08397	11.9087	12
49	.01425	70.1533	.03172	31.5284	.04920	20.3253	.06671	14.9898	.08427	11.8673	11
50	.01455	68.7501	.03201	31.2416	.04949	20.2056	.06700	14.9244	.08456	11.8262	10
51	.01484	67.4019	.03230	30.9599	.04978	20.0872	.06730	14.8596	.08485	11.7853	9
52	.01513	66.1055	.03259	30.6833	.05007	19.9702	.06759	14.7954	.08514	11.7448	8
53	.01542	64.8580	.03288	30.4116	.05037	19.8546	.06788	14.7317	.08544	11.7045	7
54	.01571	63.6567	.03317	30.1446	.05066	19.7403	.06817	14.6685	.08573	11.6645	6
55	.01600	62.4992	.03346	29.8823	.05095	19.6273	.06847	14.6059	.08602	11.6248	5
56	.01629	61.3829	.03376	29.6245	.05124	19.5156	.06876	14.5438	.08632	11.5853	4
57	.01658	60.3058	.03405	29.3711	.05153	19.4051	.06905	14.4823	.08661	11.5461	3
58	.01687	59.2659	.03434	29.1220	.05182	19.2959	.06934	14.4212	.08690	11.5072	2
59	.01716	58.2612	.03463	28.8771	.05212	19.1879	.06963	14.3607	.08720	11.4685	1
60	.01746	57.2900	.03492	28.6363	.05241	19.0811	.06993	14.3007	.08749	11.4301	0
	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	
′	89°		88°		87°		86°		85°		′

′	5° Tang	5° Cotang	6° Tang	6° Cotang	7° Tang	7° Cotang	8° Tang	8° Cotang	9° Tang	9° Cotang	′
0	.08749	11.4301	.10510	9.51436	.12278	8.14435	.14054	7.11537	.15838	6.31375	60
1	.08778	11.3919	.10540	9.48781	.12308	8.12481	.14084	7.10038	.15868	6.30189	59
2	.08807	11.3540	.10569	9.46141	.12338	8.10536	.14113	7.08546	.15898	6.29007	58
3	.08837	11.3163	.10599	9.43515	.12367	8.08600	.14143	7.07059	.15928	6.27829	57
4	.08866	11.2789	.10628	9.40904	.12397	8.06674	.14173	7.05579	.15958	6.26655	56
5	.08895	11.2417	.10657	9.38307	.12426	8.04756	.14202	7.04105	.15988	6.25486	55
6	.08925	11.2048	.10687	9.35724	.12456	8.02848	.14232	7.02637	.16017	6.24321	54
7	.08954	11.1681	.10716	9.33155	.12485	8.00948	.14262	7.01174	.16047	6.23160	53
8	.08983	11.1316	.10746	9.30599	.12515	7.99058	.14291	6.99718	.16077	6.22003	52
9	.09013	11.0954	.10775	9.28058	.12544	7.97176	.14321	6.98268	.16107	6.20851	51
10	.09042	11.0594	.10805	9.25530	.12574	7.95302	.14351	6.96823	.16137	6.19703	50
11	.09071	11.0237	.10834	9.23016	.12603	7.93438	.14381	6.95385	.16167	6.18559	49
12	.09101	10.9882	.10863	9.20516	.12633	7.91582	.14410	6.93952	.16196	6.17419	48
13	.09130	10.9529	.10893	9.18028	.12662	7.89734	.14440	6.92525	.16226	6.16283	47
14	.09159	10.9178	.10922	9.15554	.12692	7.87895	.14470	6.91104	.16256	6.15151	46
15	.09189	10.8829	.10952	9.13093	.12722	7.86064	.14499	6.89688	.16286	6.14023	45
16	.09218	10.8483	.10981	9.10646	.12751	7.84242	.14529	6.88278	.16316	6.12899	44
17	.09247	10.8139	.11011	9.08211	.12781	7.82428	.14559	6.86874	.16346	6.11779	43
18	.09277	10.7797	.11040	9.05789	.12810	7.80622	.14588	6.85475	.16376	6.10664	42
19	.09306	10.7457	.11070	9.03379	.12840	7.78825	.14618	6.84082	.16405	6.09552	41
20	.09335	10.7119	.11099	9.00983	.12869	7.77035	.14648	6.82694	.16435	6.08444	40
21	.09365	10.6783	.11128	8.98598	.12899	7.75254	.14678	6.81812	.16465	6.07340	39
22	.09394	10.6450	.11158	8.96227	.12929	7.73480	.14707	6.79936	.16495	6.06240	38
23	.09423	10.6118	.11187	8.93867	.12958	7.71715	.14737	6.78564	.16525	6.05143	37
24	.09453	10.5789	.11217	8.91520	.12988	7.69957	.14767	6.77199	.16555	6.04051	36
25	.09482	10.5462	.11246	8.89185	.13017	7.68208	.14796	6.75838	.16585	6.02962	35
26	.09511	10.5136	.11276	8.86862	.13047	7.66466	.14826	6.74483	.16615	6.01878	34
27	.09541	10.4813	.11305	8.84551	.13076	7.64732	.14856	6.73133	.16645	6.00797	33
28	.09570	10.4491	.11335	8.82252	.13106	7.63005	.14886	6.71789	.16674	5.99720	32
29	.09600	10.4172	.11364	8.79964	.13136	7.61287	.14915	6.70450	.16704	5.98646	31
30	.09629	10.3854	.11394	8.77689	.13165	7.59575	.14945	6.69116	.16734	5.97576	30
31	.09658	10.3538	.11423	8.75425	.13195	7.57872	.14975	6.67787	.16764	5.96510	29
32	.09688	10.3224	.11452	8.73172	.13224	7.56176	.15005	6.66463	.16794	5.95448	28
33	.09717	10.2913	.11482	8.70931	.13254	7.54487	.15034	6.65144	.16824	5.94390	27
34	.09746	10.2602	.11511	8.68701	.13284	7.52806	.15064	6.63831	.16854	5.93335	26
35	.09776	10.2294	.11541	8.66482	.13313	7.51132	.15094	6.62523	.16884	5.92283	25
36	.09805	10.1988	.11570	8.64275	.13343	7.49465	.15124	6.61219	.16914	5.91236	24
37	.09834	10.1683	.11600	8.62078	.13372	7.47806	.15153	6.59921	.16944	5.90191	23
38	.09864	10.1381	.11629	8.59893	.13402	7.46154	.15183	6.58627	.16974	5.89151	22
39	.09893	10.1080	.11659	8.57718	.13432	7.44509	.15213	6.57339	.17004	5.88114	21
40	.09923	10.0780	.11688	8.55555	.13461	7.42871	.15243	6.56055	.17033	5.87080	20
41	.09952	10.0483	.11718	8.53402	.13491	7.41240	.15272	6.54777	.17063	5.86051	19
42	.09981	10.0187	.11747	8.51259	.13521	7.39616	.15302	6.53503	.17093	5.85024	18
43	.10011	9.98931	.11777	8.49128	.13550	7.37999	.15332	6.52234	.17123	5.84001	17
44	.10040	9.96007	.11806	8.47007	.13580	7.36389	.15362	6.50970	.17153	5.82982	16
45	.10069	9.93101	.11836	8.44896	.13609	7.34786	.15391	6.49710	.17183	5.81966	15
46	.10099	9.90211	.11865	8.42795	.13639	7.33190	.15421	6.48456	.17213	5.80953	14
47	.10128	9.87338	.11895	8.40705	.13669	7.31600	.15451	6.47206	.17243	5.79944	13
48	.10158	9.84482	.11924	8.38625	.13698	7.30018	.15481	6.45961	.17273	5.78938	12
49	.10187	9.81641	.11954	8.36555	.13728	7.28442	.15511	6.44720	.17303	5.77936	11
50	.10216	9.78817	.11983	8.34496	.13758	7.26873	.15540	6.43484	.17333	5.76937	10
51	.10246	9.76009	.12013	8.32446	.13787	7.25310	.15570	6.42253	.17363	5.75941	9
52	.10275	9.73217	.12042	8.30406	.13817	7.23754	.15600	6.41026	.17393	5.74949	8
53	.10305	9.70441	.12072	8.28376	.13846	7.22204	.15630	6.39804	.17423	5.73960	7
54	.10334	9.67680	.12101	8.26355	.13876	7.20661	.15660	6.38587	.17453	5.72974	6
55	.10363	9.64935	.12131	8.24345	.13906	7.19125	.15689	6.37374	.17483	5.71992	5
56	.10393	9.62205	.12160	8.22344	.13935	7.17594	.15719	6.36165	.17513	5.71013	4
57	.10422	9.59490	.12190	8.20352	.13965	7.16071	.15749	6.34961	.17543	5.70037	3
58	.10452	9.56791	.12219	8.18370	.13995	7.14553	.15779	6.33761	.17573	5.69064	2
59	.10481	9.54106	.12249	8.16398	.14024	7.13042	.15809	6.32566	.17603	5.68094	1
60	.10510	9.51436	.12278	8.14435	.14054	7.11537	.15838	6.31375	.17633	5.67128	0
′	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	′
	84°		83°		82°		81°		80°		

′	10°		11°		12°		13°		14°		′
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.17633	5.67128	.19438	5.14455	.21256	4.70463	.23087	4.33148	.24933	4.01078	60
1	.17663	5.66165	.19468	5.13658	.21286	4.69791	.23117	4.32573	.24964	4.00582	59
2	.17693	5.65205	.19498	5.12862	.21316	4.69121	.23148	4.32001	.24995	4.00086	58
3	.17723	5.64248	.19529	5.12069	.21347	4.68452	.23179	4.31430	.25026	3.99592	57
4	.17753	5.63295	.19559	5.11279	.21377	4.67786	.23209	4.30860	.25056	3.99099	56
5	.17783	5.62344	.19589	5.10490	.21408	4.67121	.23240	4.30291	.25087	3.98607	55
6	.17813	5.61397	.19619	5.09704	.21438	4.66458	.23271	4.29724	.25118	3.98117	54
7	.17843	5.60452	.19649	5.08921	.21469	4.65797	.23301	4.29159	.25149	3.97627	53
8	.17873	5.59511	.19680	5.08139	.21499	4.65138	.23332	4.28595	.25180	3.97139	52
9	.17903	5.58573	.19710	5.07360	.21529	4.64480	.23363	4.28032	.25211	3.96651	51
10	.17933	5.57638	.19740	5.06584	.21560	4.63825	.23393	4.27471	.25242	3.96165	50
11	.17963	5.56706	.19770	5.05809	.21590	4.63171	.23424	4.26911	.25273	3.95680	49
12	.17993	5.55777	.19801	5.05037	.21621	4.62518	.23455	4.26352	.25304	3.95196	48
13	.18023	5.54851	.19831	5.04267	.21651	4.61868	.23485	4.25795	.25335	3.94713	47
14	.18053	5.53927	.19861	5.03499	.21682	4.61219	.23516	4.25239	.25366	3.94232	46
15	.18083	5.53007	.19891	5.02734	.21712	4.60572	.23547	4.24685	.25397	3.93751	45
16	.18113	5.52090	.19921	5.01971	.21743	4.59927	.23578	4.24132	.25428	3.93271	44
17	.18143	5.51176	.19952	5.01210	.21773	4.59283	.23608	4.23580	.25459	3.92793	43
18	.18173	5.50264	.19982	5.00451	.21804	4.58641	.23639	4.23030	.25490	3.92316	42
19	.18203	5.49356	.20012	4.99695	.21834	4.58001	.23670	4.22481	.25521	3.91839	41
20	.18233	5.48451	.20042	4.98940	.21864	4.57363	.23700	4.21933	.25552	3.91364	40
21	.18263	5.47548	.20073	4.98188	.21895	4.56726	.23731	4.21387	.25583	3.90890	39
22	.18293	5.46648	.20103	4.97438	.21925	4.56091	.23762	4.20842	.25614	3.90417	38
23	.18323	5.45751	.20133	4.96690	.21956	4.55458	.23793	4.20298	.25645	3.89945	37
24	.18353	5.44857	.20164	4.95945	.21986	4.54826	.23823	4.19756	.25676	3.89474	36
25	.18384	5.43966	.20194	4.95201	.22017	4.54196	.23854	4.19215	.25707	3.89004	35
26	.18414	5.43077	.20224	4.94460	.22047	4.53568	.23885	4.18675	.25738	3.88536	34
27	.18444	5.42192	.20254	4.93721	.22078	4.52941	.23916	4.18137	.25769	3.88068	33
28	.18474	5.41309	.20285	4.92984	.22108	4.52316	.23946	4.17600	.25800	3.87601	32
29	.18504	5.40429	.20315	4.92249	.22139	4.51693	.23977	4.17064	.25831	3.87136	31
30	.18534	5.39552	.20345	4.91516	.22169	4.51071	.24008	4.16530	.25862	3.86671	30
31	.18564	5.38677	.20376	4.90785	.22200	4.50451	.24039	4.15997	.25893	3.86208	29
32	.18594	5.37805	.20406	4.90056	.22231	4.49832	.24069	4.15465	.25924	3.85745	28
33	.18624	5.36936	.20436	4.89330	.22261	4.49215	.24100	4.14934	.25955	3.85284	27
34	.18654	5.36070	.20466	4.88605	.22292	4.48600	.24131	4.14405	.25986	3.84824	26
35	.18684	5.35206	.20497	4.87882	.22322	4.47986	.24162	4.13877	.26017	3.84364	25
36	.18714	5.34345	.20527	4.87162	.22353	4.47374	.24193	4.13350	.26048	3.83906	24
37	.18745	5.33487	.20557	4.86444	.22383	4.46764	.24223	4.12825	.26079	3.83449	23
38	.18775	5.32631	.20588	4.85727	.22414	4.46155	.24254	4.12301	.26110	3.82992	22
39	.18805	5.31778	.20618	4.85013	.22444	4.45548	.24285	4.11778	.26141	3.82537	21
40	.18835	5.30928	.20648	4.84300	.22475	4.44942	.24316	4.11256	.26172	3.82083	20
41	.18865	5.30080	.20679	4.83590	.22505	4.44338	.24347	4.10736	.26203	3.81630	19
42	.18895	5.29235	.20709	4.82882	.22536	4.43735	.24377	4.10216	.26235	3.81177	18
43	.18925	5.28393	.20739	4.82175	.22567	4.43134	.24408	4.09699	.26266	3.80726	17
44	.18955	5.27553	.20770	4.81471	.22597	4.42534	.24439	4.09182	.26297	3.80276	16
45	.18986	5.26715	.20800	4.80769	.22628	4.41936	.24470	4.08666	.26328	3.79827	15
46	.19016	5.25880	.20830	4.80068	.22658	4.41340	.24501	4.08152	.26359	3.79378	14
47	.19046	5.25048	.20861	4.79370	.22689	4.40745	.24532	4.07639	.26390	3.78931	13
48	.19076	5.24218	.20891	4.78673	.22719	4.40152	.24562	4.07127	.26421	3.78485	12
49	.19106	5.23391	.20921	4.77978	.22750	4.39560	.24593	4 06616	.26452	3.78040	11
50	.19136	5.22566	.20952	4.77286	.22781	4.38969	.24624	4.06107	.26483	3.77595	10
51	.19166	5.21744	.20982	4.76595	.22811	4.38381	.24655	4.05599	.26515	3.77152	9
52	.19197	5.20925	.21013	4.75906	.22842	4.37793	.24686	4.05092	.26546	3.76709	8
53	.19227	5.20107	.21043	4.75219	.22872	4.37207	.24717	4.04586	.26577	3.76268	7
54	.19257	5.19293	.21073	4.74534	.22903	4.36623	.24747	4.04081	.26608	3.75828	6
55	.19287	5.18480	.21104	4.73851	.22934	4.36040	.24778	4.03578	.26639	3.75388	5
56	.19317	5.17671	.21134	4.73170	.22964	4.35459	.24809	4.03076	.26670	3.74950	4
57	.19347	5.16863	.21164	4.72490	.22995	4.34879	.24840	4.02574	.26701	3.74512	3
58	.19378	5.16058	.21195	4.71813	.23026	4.34300	.24871	4.02074	.26733	3.74075	2
59	.19408	5.15256	.21225	4.71137	.23056	4.33723	.24902	4.01576	.26764	3.73640	1
60	.19438	5.14455	.21256	4.70463	.23087	4.33148	.24933	4.01078	.26795	3.73205	0
	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	
′	79°		78°		77°		76°		75°		′

′	15°		16°		17°		18°		19°		′
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.26795	3.73205	.28675	3.48741	.30573	3.27085	.32492	3.07768	.34433	2.90421	60
1	.26826	3.72771	.28706	3.48359	.30605	3.26745	.32524	3.07464	.34465	2.90147	59
2	.26857	3.72338	.28738	3.47977	.30637	3.26406	.32556	3.07160	.34498	2.89873	58
3	.26888	3.71907	.28769	3.47596	.30669	3.26067	.32588	3.06857	.34530	2.89600	57
4	.26920	3.71476	.28800	3.47216	.30700	3.25729	.32621	3.06554	.34563	2.89327	56
5	.26951	3.71046	.28832	3.46837	.30732	3.25392	.32653	3.06252	.34596	2.89055	55
6	.26982	3.70616	.28864	3.46458	.30764	3.25055	.32685	3.05950	.34628	2.88783	54
7	.27013	3.70188	.28895	3.46080	.30796	3.24719	.32717	3.05649	.34661	2.88511	53
8	.27044	3.69761	.28927	3.45703	.30828	3.24383	.32749	3.05349	.34693	2.88240	52
9	.27076	3.69335	.28958	3.45327	.30860	3.24049	.32782	3.05049	.34726	2.87970	51
10	.27107	3.68909	.28990	3.44951	.30891	3.23714	.32814	3.04749	.34758	2.87700	50
11	.27138	3.68485	.29021	3.44576	.30923	3.23381	.32846	3.04450	.34791	2.87430	49
12	.27169	3.68061	.29053	3.44202	.30955	3.23048	.32878	3.04152	.34824	2.87161	48
13	.27201	3.67638	.29084	3.43829	.30987	3.22715	.32911	3.03854	.34856	2.86892	47
14	.27232	3.67217	.29116	3.43456	.31019	3.22384	.32943	3.03556	.34889	2.86624	46
15	.27263	3.66796	.29147	3.43084	.31051	3.22053	.32975	3.03260	.34922	2.86356	45
16	.27294	3.66376	.29179	3.42713	.31083	3.21722	.33007	3.02963	.34954	2.86089	44
17	.27326	3.65957	.29210	3.42343	.31115	3.21392	.33040	3.02667	.34987	2.85822	43
18	.27357	3.65538	.29242	3.41973	.31147	3.21063	.33072	3.02372	.35020	2.85555	42
19	.27388	3.65121	.29274	3.41604	.31178	3.20734	.33104	3.02077	.35052	2.85289	41
20	.27419	3.64705	.29305	3.41236	.31210	3.20406	.33136	3.01783	.35085	2.85023	40
21	.27451	3.64289	.29337	3.40869	.31242	3.20079	.33169	3.01489	.35118	2.84758	39
22	.27482	3.63874	.29368	3.40502	.31274	3.19752	.33201	3.01196	.35150	2.84494	38
23	.27513	3.63461	.29400	3.40136	.31306	3.19426	.33233	3.00903	.35183	2.84229	37
24	.27545	3.63048	.29432	3.39771	.31338	3.19100	.33266	3.00611	.35216	2.83965	36
25	.27576	3.62636	.29463	3.39406	.31370	3.18775	.33298	3.00319	.35248	2.83702	35
26	.27607	3.62224	.29495	3.39042	.31402	3.18451	.33330	3.00028	.35281	2.83439	34
27	.27638	3.61814	.29526	3.38679	.31434	3.18127	.33363	2.99738	.35314	2.83176	33
28	.27670	3.61405	.29558	3.38317	.31466	3.17804	.33395	2.99447	.35346	2.82914	32
29	.27701	3.60996	.29590	3.37955	.31498	3.17481	.33427	2.99158	.35379	2.82653	31
30	.27732	3.60588	.29621	3.37594	.31530	3.17159	.33460	2.98868	.35412	2.82391	30
31	.27764	3.60181	.29653	3.37234	.31562	3.16838	.33492	2.98580	.35445	2.82130	29
32	.27795	3.59775	.29685	3.36875	.31594	3.16517	.33524	2.98292	.35477	2.81870	28
33	.27826	3.59370	.29716	3.36516	.31626	3.16197	.33557	2.98004	.35510	2.81610	27
34	.27858	3.58966	.29748	3.36158	.31658	3.15877	.33589	2.97717	.35543	2.81350	26
35	.27889	3.58562	.29780	3.35800	.31690	3.15558	.33621	2.97430	.35576	2.81091	25
36	.27921	3.58160	.29811	3.35443	.31722	3.15240	.33654	2.97144	.35608	2.80833	24
37	.27952	3.57758	.29843	3.35087	.31754	3.14922	.33686	2.96858	.35641	2.80574	23
38	.27983	3.57357	.29875	3.34732	.31786	3.14605	.33718	2.96573	.35674	2.80316	22
39	.28015	3.56957	.29906	3.34377	.31818	3.14288	.33751	2.96288	.35707	2.80059	21
40	.28046	3.56557	.29938	3.34023	.31850	3.13972	.33783	2.96004	.35740	2.79802	20
41	.28077	3.56159	.29970	3.33670	.31882	3.13656	.33816	2.95721	.35772	2.79545	19
42	.28109	3.55761	.30001	3.33317	.31914	3.13341	.33848	2.95437	.35805	2.79289	18
43	.28140	3.55364	.30033	3.32965	.31946	3.13027	.33881	2.95155	.35838	2.79033	17
44	.28172	3.54968	.30065	3.32614	.31978	3.12713	.33913	2.94872	.35871	2.78778	16
45	.28203	3.54573	.30097	3.32264	.32010	3.12400	.33945	2.94591	.35904	2.78523	15
46	.28234	3.54179	.30128	3.31914	.32042	3.12087	.33978	2.94309	.35937	2.78269	14
47	.28266	3.53785	.30160	3.31565	.32074	3.11775	.34010	2.94028	.35969	2.78014	13
48	.28297	3.53393	.30192	3.31216	.32106	3.11464	.34043	2.93748	.36002	2.77761	12
49	.28329	3.53001	.30224	3.30868	.32139	3.11153	.34075	2.93468	.36035	2.77507	11
50	.28360	3.52609	.30255	3.30521	.32171	3.10842	.34108	2.93189	.36068	2.77254	10
51	.28391	3.52219	.30287	3.30174	.32203	3.10532	.34140	2.92910	.36101	2.77002	9
52	.28423	3.51829	.30319	3.29829	.32235	3.10223	.34173	2.92632	.36134	2.76750	8
53	.28454	3.51441	.30351	3.29483	.32267	3.09914	.34205	2.92354	.36167	2.76498	7
54	.28486	3.51053	.30382	3.29139	.32299	3.09606	.34238	2.92076	.36199	2.76247	6
55	.28517	3.50666	.30414	3.28795	.32331	3.09298	.34270	2.91799	.36232	2.75996	5
56	.28549	3.50279	.30446	3.28452	.32363	3.08991	.34303	2.91523	.36265	2.75746	4
57	.28580	3.49894	.30478	3.28109	.32396	3.08685	.34335	2.91246	.36298	2.75496	3
58	.28612	3.49509	.30509	3.27767	.32428	3.08379	.34368	2.90971	.36331	2.75246	2
59	.28643	3.49125	.30541	3.27426	.32460	3.08073	.34400	2.90696	.36364	2.74997	1
60	.28675	3.48741	.30573	3.27085	.32492	3.07768	.34433	2.90421	.36397	2.74748	0
	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	
′	74°		73°		72°		71°		70°		′

′	20°		21°		22°		23°		24°		′
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.36397	2.74748	.38386	2.60509	.40403	2.47509	.42447	2.35585	.44523	2.24604	60
1	.36430	2.74499	.38420	2.60283	.40436	2.47302	.42482	2.35395	.44558	2.24428	59
2	.36463	2.74251	.38453	2.60057	.40470	2.47095	.42516	2.35205	.44593	2.24252	58
3	.36496	2.74004	.38487	2.59831	.40504	2.46888	.42551	2.35015	.44627	2.24077	57
4	.36529	2.73756	.38520	2.59606	.40538	2.46682	.42585	2.34825	.44662	2.23902	56
5	.36562	2.73509	.38553	2.59381	.40572	2.46476	.42619	2.34636	.44697	2.23727	55
6	.36595	2.73263	.38587	2.59156	.40606	2.46270	.42654	2.34447	.44732	2.23553	54
7	.36628	2.73017	.38620	2.58932	.40640	2.46065	.42688	2.34258	.44767	2.23378	53
8	.36661	2.72771	.38654	2.58708	.40674	2.45860	.42722	2.34069	.44802	2.23204	52
9	.36694	2.72526	.38687	2.58484	.40707	2.45655	.42757	2.33881	.44837	2.23030	51
10	.36727	2.72281	.38721	2.58261	.40741	2.45451	.42791	2.33693	.44872	2.22857	50
11	.36760	2.72036	.38754	2.58038	.40775	2.45246	.42826	2.33505	.44907	2.22683	49
12	.36793	2.71792	.38787	2.57815	.40809	2.45043	.42860	2.33317	.44942	2.22510	48
13	.36826	2.71548	.38821	2.57593	.40843	2.44839	.42894	2.33130	.44977	2.22337	47
14	.36859	2.71305	.38854	2.57371	.40877	2.44636	.42929	2.32943	.45012	2.22164	46
15	.36892	2.71062	.38888	2.57150	.40911	2.44433	.42963	2.32756	.45047	2.21992	45
16	.36925	2.70819	.38921	2.56928	.40945	2.44230	.42998	2.32570	.45082	2.21819	44
17	.36958	2.70577	.38955	2.56707	.40979	2.44027	.43032	2.32383	.45117	2.21647	43
18	.36991	2.70335	.38988	2.56487	.41013	2.43825	.43067	2.32197	.45152	2.21475	42
19	.37024	2.70094	.39022	2.56266	.41047	2.43623	.43101	2.32012	.45187	2.21304	41
20	.37057	2.69853	.39055	2.56046	.41081	2.43422	.43136	2.31826	.45222	2.21132	40
21	.37090	2.69612	.39089	2.55827	.41115	2.43220	.43170	2.31641	.45257	2.20961	39
22	.37123	2.69371	.39122	2.55608	.41149	2.43019	43205	2.31456	.45292	2.20790	38
23	.37157	2.69131	.39156	2.55389	.41183	2.42819	.43230	2.31271	.45327	2.20619	37
24	.37190	2.68892	.39190	2.55170	.41217	2.42618	.43274	2.31086	.45362	2.20449	36
25	.37223	2.68653	.39223	2.54952	.41251	2 42418	.43308	2.30902	.45397	2.20278	35
26	.37256	2.68414	.39257	2.54734	.41285	2.42218	.43343	2.30718	.45432	2.20108	34
27	.37289	2.68175	.39290	2.54516	.41319	2.42019	.43378	2.30534	.45467	2.19938	33
28	.37322	2.67937	.39324	2.54299	.41353	2.41819	.43412	2.30351	.45502	2.19769	32
29	.37355	2.67700	.39357	2.54082	.41387	2.41620	.43447	2.30167	.45538	2.19599	31
30	.37388	2.67462	.39391	2.53865	.41421	2.41421	.43481	2.29984	.45573	2.19430	30
31	.37422	2.67225	.39425	2.53648	.41455	2.41223	.43516	2.29801	.45608	2.19261	29
32	.37455	2.66989	.39458	2.53432	.41490	2.41025	.43550	2.29619	.45643	2.19092	28
33	.37488	2.66752	.39492	2.53217	.41524	2.40827	.43585	2.29437	.45678	2.18923	27
34	.37521	2.66516	.39526	2.53001	.41558	2.40629	.43620	2.29254	.45713	2.18755	26
35	.37554	2.66281	.39559	2.52786	.41592	2.40432	.43654	2.29073	.45748	2.18587	25
36	.37588	2.66046	.39593	2.52571	.41626	2.40235	.43689	2.28891	.45784	2.18419	24
37	.37621	2.65811	.39626	2.52357	.41660	2.40038	.43724	2.28710	.45819	2.18251	23
38	.37654	2.65576	.39660	2.52142	.41694	2.39841	.43758	2.28528	.45854	2.18084	22
39	.37687	2.65342	.39694	2.51929	.41728	2.39645	.43793	2.28348	.45889	2.17916	21
40	.37720	2.65109	.39727	2.51715	.41763	2.39449	.43828	2.28167	.45924	2.17749	20
41	.37754	2.64875	.39761	2.51502	.41797	2.39253	.43862	2.27987	.45960	2.17582	19
42	.37787	2.64642	.39795	2.51289	.41831	2.39058	.43897	2.27806	.45995	2.17416	18
43	.37820	2.64410	.39829	2.51076	.41865	2.38863	.43932	2.27626	.46030	2.17249	17
44	.37853	2.64177	.39862	2.50864	.41899	2.38668	.43966	2.27447	.46065	2.17083	16
45	.37887	2.63945	.39896	2.50652	.41933	2.38473	.44001	2.27267	.46101	2.16917	15
46	.37920	2.63714	.39930	2.50440	.41968	2.38279	.44036	2.27088	.46136	2.16751	14
47	.37953	2.63483	.39963	2.50229	.42002	2.38084	.44071	2.26909	.46171	2.16585	13
48	.37986	2.63252	.39997	2.50018	.42036	2.37891	.44105	2.26730	.46206	2.16420	12
49	.38020	2.63021	.40031	2.49807	.42070	2.37697	.44140	2.26552	.46242	2.16255	11
50	.38053	2.62791	.40065	2.49597	.42105	2.37504	.44175	2.26374	.46277	2.16090	10
51	.38086	2.62561	.40098	2.49386	.42139	2.37311	.44210	2.26196	.46312	2.15925	9
52	.38120	2.62332	.40132	2.49177	.42173	2.37118	.44244	2.26018	.46348	2.15760	8
53	.38153	2.62103	.40166	2.48967	.42207	2.36925	.44279	2.25840	.46383	2.15596	7
54	.38186	2.61874	.40200	2.48758	.42242	2.36733	.44314	2.25663	.46418	2.15432	6
55	.38220	2.61646	.40234	2.48549	.42276	2.36541	.44349	2.25486	.46454	2.15268	5
56	.38253	2.61418	.40267	2.48340	.42310	2.36349	.44384	2.25309	.46489	2.15104	4
57	.38286	2.61190	.40301	2.48132	.42345	2.36158	.44418	2.25132	.46525	2.14940	3
58	.38320	2.60963	.40335	2.47924	.42379	2.35967	.44453	2.24956	.46560	2.14777	2
59	.38353	2.60736	.40369	2.47716	.42413	2.35776	.44488	2.24780	.46595	2.14614	1
60	.38386	2.60509	.40403	2.47509	.42447	2.35585	.44523	2.24604	.46631	2.14451	0
	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	
′	69°		68°		67°		66°		65°		′

′	25°		26°		27°		28°		29°		′
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.46631	2.14451	.48773	2.05030	.50953	1.96261	.53171	1.88073	.55431	1.80405	60
1	.46666	2.14288	.48809	2.04879	.50989	1.96120	.53208	1.87941	.55469	1.80281	59
2	.46702	2.14125	.48845	2.04728	.51026	1.95979	.53246	1.87809	.55507	1.80158	58
3	.46737	2.13963	.48881	2.04577	.51063	1.95838	.53283	1.87677	.55545	1.80034	57
4	.46772	2.13801	.48917	2.04426	.51099	1.95698	.53320	1.87546	.55583	1.79911	56
5	.46808	2.13639	.48953	2.04276	.51136	1.95557	.53358	1.87415	.55621	1.79788	55
6	.46843	2.13477	.48989	2.04125	.51173	1.95417	.53395	1.87283	.55659	1.79665	54
7	.46879	2.13316	.49026	2.03975	.51209	1.95277	.53432	1.87152	.55697	1.79542	53
8	.46914	2.13154	.49062	2.03825	.51246	1.95137	.53470	1.87021	.55736	1.79419	52
9	.46950	2.12993	.49098	2.03675	.51283	1.94997	.53507	1.86891	.55774	1.79296	51
10	.46985	2.12832	.49134	2.03526	.51319	1.94858	.53545	1.86760	.55812	1.79174	50
11	.47021	2.12671	.49170	2.03376	.51356	1.94718	.53582	1.86630	.55850	1.79051	49
12	.47056	2.12511	.49206	2.03227	.51393	1.94579	.53620	1.86499	.55888	1.78929	48
13	.47092	2.12350	.49242	2.03078	.51430	1.94440	.53657	1.86369	.55926	1.78807	47
14	.47128	2.12190	.49278	2.02929	.51467	1.94301	.53694	1.86239	.55964	1.78685	46
15	.47163	2.12030	.49315	2.02780	.51503	1.94162	.53732	1.86109	.56003	1.78563	45
16	.47199	2.11871	.49351	2.02631	.51540	1.94023	.53769	1.85979	.56041	1.78441	44
17	.47234	2.11711	.49387	2.02483	.51577	1.93885	.53807	1.85850	.56079	1.78319	43
18	.47270	2.11552	.49423	2.02335	.51614	1.93746	.53844	1.85720	.56117	1.78198	42
19	.47305	2.11392	.49459	2.02187	.51651	1.93608	.53882	1.85591	.56156	1.78077	41
20	.47341	2.11233	.49495	2.02039	.51688	1.93470	.53920	1.85462	.56194	1.77955	40
21	.47377	2.11075	.49532	2.01891	.51724	1.93332	.53957	1.85333	.56232	1.77834	39
22	.47412	2.10916	.49568	2.01743	.51761	1.93195	.53995	1.85204	.56270	1.77713	38
23	.47448	2.10758	.49604	2.01596	.51798	1.93057	.54032	1.85075	.56309	1.77592	37
24	.47483	2.10600	.49640	2.01449	.51835	1.92920	.54070	1.84946	.56347	1.77471	36
25	.47519	2.10442	.49677	2.01302	.51872	1.92782	.54107	1.84818	.56385	1.77351	35
26	.47555	2.10284	.49713	2.01155	.51909	1.92645	.54145	1.84689	.56424	1.77230	34
27	.47590	2.10126	.49749	2.01008	.51946	1.92508	.54183	1.84561	.56462	1.77110	33
28	.47626	2.09969	.49786	2.00862	.51983	1.92371	.54220	1.84433	.56501	1.76990	32
29	.47662	2.09811	.49822	2.00715	.52020	1.92235	.54258	1.84305	.56539	1.76869	31
30	.47698	2.09654	.49858	2.00569	.52057	1.92098	.54296	1.84177	.56577	1.76749	30
31	.47733	2.09498	.49894	2.00423	.52094	1.91962	.54333	1.84049	.56616	1.76629	29
32	.47769	2.09341	.49931	2.00277	.52131	1.91826	.54371	1.83922	.56654	1.76510	28
33	.47805	2.09184	.49967	2.00131	.52168	1.91690	.54409	1.83794	.56693	1.76390	27
34	.47840	2.09028	.50004	1.99986	.52205	1.91554	.54446	1.83667	.56731	1.76271	26
35	.47876	2.08872	.50040	1.99841	.52242	1.91418	.54484	1.83540	.56769	1.76151	25
36	.47912	2.08716	.50076	1.99695	.52279	1.91282	.54522	1.83413	.56808	1.76032	24
37	.47948	2.08560	.50113	1.99550	.52316	1.91147	.54560	1.83286	.56846	1.75913	23
38	.47984	2.08405	.50149	1.99406	.52353	1.91012	.54597	1.83159	.56885	1.75794	22
39	.48019	2.08250	.50185	1.99261	.52390	1.90876	.54635	1.83033	.56923	1.75675	21
40	.48055	2.08094	.50222	1.99116	.52427	1.90741	.54673	1.82906	.56962	1.75556	20
41	.48091	2.07939	.50258	1.98972	.52464	1.90607	.54711	1.82780	.57000	1.75437	19
42	.48127	2.07785	.50295	1.98828	.52501	1.90472	.54748	1.82654	.57039	1.75319	18
43	.48163	2.07630	.50331	1.98684	.52538	1.90337	.54786	1.82528	.57078	1.75200	17
44	.48198	2.07476	.50368	1.98540	.52575	1.90203	.54824	1.82402	.57116	1.75082	16
45	.48234	2.07321	.50404	1.98396	.52613	1.90069	.54862	1.82276	.57155	1.74964	15
46	.48270	2.07167	.50441	1.98253	.52650	1.89935	.54900	1.82150	.57193	1.74846	14
47	.48306	2.07014	.50477	1.98110	.52687	1.89801	.54938	1.82025	.57232	1.74728	13
48	.48342	2.06860	.50514	1.97966	.52724	1.89667	.54975	1.81899	.57271	1.74610	12
49	.48378	2.06706	.50550	1.97823	.52761	1.89533	.55013	1.81774	.57309	1.74492	11
50	.48414	2.06553	.50587	1.97681	.52798	1.89400	.55051	1.81649	.57348	1.74375	10
51	.48450	2.06400	.50623	1.97538	.52836	1.89266	.55089	1.81524	.57386	1.74257	9
52	.48486	2.06247	.50660	1.97395	.52873	1.89133	.55127	1.81399	.57425	1.74140	8
53	.48521	2.06094	.50696	1.97253	.52910	1.89000	.55165	1.81274	.57464	1.74022	7
54	.48557	2.05942	.50733	1.97111	.52947	1.88867	.55203	1.81150	.57503	1.73905	6
55	.48593	2.05790	.50769	1.96969	.52985	1.88734	.55241	1.81025	.57541	1.73788	5
56	.48629	2.05637	.50806	1.96827	.53022	1.88602	.55279	1.80901	.57580	1.73671	4
57	.48665	2.05485	.50843	1.96685	.53059	1.88469	.55317	1.80777	.57619	1.73555	3
58	.48701	2.05333	.50879	1.96544	.53096	1.88337	.55355	1.80653	.57657	1.73438	2
59	.48737	2.05182	.50916	1.96402	.53134	1.88205	.55393	1.80529	.57696	1.73321	1
60	.48773	2.05030	.50953	1.96261	.53171	1.88073	.55431	1.80405	.57735	1.73205	0
	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	
′	64°		63°		62°		61°		60°		′

′	30° Tang	30° Cotang	31° Tang	31° Cotang	32° Tang	32° Cotang	33° Tang	33° Cotang	34° Tang	34° Cotang	′
0	.57735	1.73205	.60086	1.66428	.62487	1.60033	.64941	1.53986	.67451	1.48256	60
1	.57774	1.73089	.60126	1.66318	.62527	1.59930	.64982	1.53888	.67493	1.48163	59
2	.57813	1.72973	.60165	1.66209	.62568	1.59826	.65024	1.53791	.67536	1.48070	58
3	.57851	1.72857	.60205	1.66099	.62608	1.59723	.65065	1.53693	.67578	1.47977	57
4	.57890	1.72741	.60245	1.65990	.62649	1.59620	.65106	1.53595	.67620	1.47885	56
5	.57929	1.72625	.60284	1.65881	.62689	1.59517	.65148	1.53497	.67663	1.47792	55
6	.57968	1.72509	.60324	1.65772	.62730	1.59414	.65189	1.53400	.67705	1.47699	54
7	.58007	1.72393	.60364	1.65663	.62770	1.59311	.65231	1.53302	.67748	1.47607	53
8	.58046	1.72278	.60403	1.65554	.62811	1.59208	.65272	1.53205	.67790	1.47514	52
9	.58085	1.72163	.60443	1.65445	.62852	1.59105	.65314	1.53107	.67832	1.47422	51
10	.58124	1.72047	.60483	1.65337	.62892	1.59002	.65355	1.53010	.67875	1.47330	50
11	.58162	1.71932	.60522	1.65228	.62933	1.58900	.65397	1.52913	.67917	1.47238	49
12	.58201	1.71817	.60562	1.65120	.62973	1.58797	.65438	1.52816	.67960	1.47146	48
13	.58240	1.71702	.60602	1.65011	.63014	1.58695	.65480	1.52719	.68002	1.47053	47
14	.58279	1.71588	.60642	1.64903	.63055	1.58593	.65521	1.52622	.68045	1.46962	46
15	.58318	1.71473	.60681	1.64795	.63095	1.58490	.65563	1.52525	.68088	1.46870	45
16	.58357	1.71358	.60721	1.64687	.63136	1.58388	.65604	1.52429	.68130	1.46778	44
17	.58396	1.71244	.60761	1.64579	.63177	1.58286	.65646	1.52332	.68173	1.46686	43
18	.58435	1.71129	.60801	1.64471	.63217	1.58184	.65688	1.52235	.68215	1.46595	42
19	.58474	1.71015	.60841	1.64363	.63258	1.58083	.65729	1.52139	.68258	1.46503	41
20	.58513	1.70901	.60881	1.64256	.63299	1.57981	.65771	1.52043	.68301	1.46411	40
21	.58552	1.70787	.60921	1.64148	.63340	1.57879	.65813	1.51946	.68343	1.46320	39
22	.58591	1.70673	.60960	1.64041	.63380	1.57778	.65854	1.51850	.68386	1.46229	38
23	.58631	1.70560	.61000	1.63934	.63421	1.57676	.65896	1.51754	.68429	1.46137	37
24	.58670	1.70446	.61040	1.63826	.63462	1.57575	.65938	1.51658	.68471	1.46046	36
25	.58709	1.70332	.61080	1.63719	.63503	1.57474	.65980	1.51562	.68514	1.45955	35
26	.58748	1.70219	.61120	1.63612	.63544	1.57372	.66021	1.51466	.68557	1.45864	34
27	.58787	1.70106	.61160	1.63505	.63584	1.57271	.66063	1.51370	.68600	1.45773	33
28	.58826	1.69992	.61200	1.63398	.63625	1.57170	.66105	1.51275	.68642	1.45682	32
29	.58865	1.69879	.61240	1.63292	.63666	1.57069	.66147	1.51179	.68685	1.45592	31
30	.58905	1.69766	.61280	1.63185	.63707	1.56969	.66189	1.51084	.68728	1.45501	30
31	.58944	1.69653	.61320	1.63079	.63748	1.56868	.66230	1.50988	.68771	1.45410	29
32	.58983	1.69541	.61360	1.62972	.63789	1.56767	.66272	1.50893	.68814	1.45320	28
33	.59022	1.69428	.61400	1.62866	.63830	1.56667	.66314	1.50797	.68857	1.45229	27
34	.59061	1.69316	.61440	1.62760	.63871	1.56566	.66356	1.50702	.68900	1.45139	26
35	.59101	1.69203	.61480	1.62654	.63912	1.56466	.66398	1.50607	.68942	1.45049	25
36	.59149	1.69091	.61520	1.62548	.63953	1.56366	.66440	1.50512	.68985	1.44958	24
37	.59179	1.68979	.61561	1.62442	.63994	1.56265	.66482	1.50417	.69028	1.44868	23
38	.59218	1.68866	.61601	1.62336	.64035	1.56165	.66524	1.50322	.69071	1.44778	22
39	.59258	1.68754	.61641	1.62230	.64076	1.56065	.66566	1.50228	.69114	1.44688	21
40	.59297	1.68643	.61681	1.62125	.64117	1.55966	.66608	1.50133	.69157	1.44598	20
41	.59336	1.68531	.61721	1.62019	.64158	1.55866	.66650	1.50038	.69200	1.44508	19
42	.59376	1.68419	.61761	1.61914	.64199	1.55766	.66692	1.49944	.69243	1.44418	18
43	.59415	1.68308	.61801	1.61808	.64240	1.55666	.66734	1.49849	.69286	1.44329	17
44	.59454	1.68196	.61842	1.61703	.64281	1.55567	.66776	1.49755	.69329	1.44239	16
45	.59494	1.68085	.61882	1.61598	.64322	1.55467	.66818	1.49661	.69372	1.44149	15
46	.59533	1.67974	.61922	1.61493	.64363	1.55368	.66860	1.49566	.69416	1.44060	14
47	.59573	1.67863	.61962	1.61388	.64404	1.55269	.66902	1.49472	.69459	1.43970	13
48	.59612	1.67752	.62003	1.61283	.64446	1.55170	.66944	1.49378	.69502	1.43881	12
49	.59651	1.67641	.62043	1.61179	.64487	1.55071	.66986	1.49284	.69545	1.43792	11
50	.59691	1.67530	.62083	1.61074	.64528	1.54972	.67028	1.49190	.69588	1.43703	10
51	.59730	1.67419	.62124	1.60970	.64569	1.54873	.67071	1.49097	.69631	1.43614	9
52	.59770	1.67309	.62164	1.60865	.64610	1.54774	.67113	1.49003	.69675	1.43525	8
53	.59809	1.67198	.62204	1.60761	.64652	1.54675	.67155	1.48909	.69718	1.43436	7
54	.59849	1.67088	.62245	1.60657	.64693	1.54576	.67197	1.48816	.69761	1.43347	6
55	.59888	1.66978	.62285	1.60553	.64734	1.54478	.67239	1.48722	.69804	1.43258	5
56	.59928	1.66867	.62325	1.60449	.64775	1.54379	.67282	1.48629	.69847	1.43169	4
57	.59967	1.66757	.62366	1.60345	.64817	1.54281	.67324	1.48536	.69891	1.43080	3
58	.60007	1.66647	.62406	1.60241	.64858	1.54183	.67366	1.48442	.69934	1.42992	2
59	.60046	1.66538	.62446	1.60137	.64899	1.54085	.67409	1.48349	.69977	1.42903	1
60	.60086	1.66428	.62487	1.60033	.64941	1.53986	.67451	1.48256	.70021	1.42815	0
′	59° Cotang	59° Tang	58° Cotang	58° Tang	57° Cotang	57° Tang	56° Cotang	56° Tang	55° Cotang	55° Tang	′

′	35° Tang	35° Cotang	36° Tang	36° Cotang	37° Tang	37° Cotang	38° Tang	38° Cotang	39° Tang	39° Cotang	′
0	.70021	1.42815	.72654	1.37638	.75355	1.32704	.78129	1.27994	.80978	1.23490	60
1	.70064	1.42726	.72699	1.37554	.75401	1.32624	.78175	1.27917	.81027	1.23416	59
2	.70107	1.42638	.72743	1.37470	.75447	1.32544	.78222	1.27841	.81075	1.23343	58
3	.70151	1.42550	.72788	1.37386	.75492	1.32464	.78269	1.27764	.81123	1.23270	57
4	.70194	1.42462	.72832	1.37302	.75538	1.32384	.78316	1.27688	.81171	1.23196	56
5	.70238	1.42374	.72877	1.37218	.75584	1.32304	.78363	1.27611	.81220	1.23123	55
6	.70281	1.42286	.72921	1.37134	.75629	1.32224	.78410	1.27535	.81268	1.23050	54
7	.70325	1.42198	.72966	1.37050	.75675	1.32144	.78457	1.27458	.81316	1.22977	53
8	.70368	1.42110	.73010	1.36967	.75721	1.32064	.78504	1.27382	.81364	1.22904	52
9	.70412	1.42022	.73055	1.36883	.75767	1.31984	.78551	1.27306	.81413	1.22831	51
10	.70455	1.41934	.73100	1.36800	.75812	1.31904	.78598	1.27230	.81461	1.22758	50
11	.70499	1.41847	.73144	1.36716	.75858	1.31825	.78645	1.27153	.81510	1.22685	49
12	.70542	1.41759	.73189	1.36633	.75904	1.31745	.78692	1.27077	.81558	1.22612	48
13	.70586	1.41672	.73234	1.36549	.75950	1.31666	.78739	1.27001	.81606	1.22539	47
14	.70629	1.41584	.73278	1.36466	.75996	1.31586	.78786	1.26925	.81655	1.22467	46
15	.70673	1.41497	.73323	1.36383	.76042	1.31507	.78834	1.26849	.81703	1.22394	45
16	.70717	1.41409	.73368	1.36300	.76088	1.31427	.78881	1.26774	.81752	1.22321	44
17	.70760	1.41322	.73413	1.36217	.76134	1.31348	.78928	1.26698	.81800	1.22249	43
18	.70804	1.41235	.73457	1.36134	.76180	1.31269	.78975	1.26622	.81849	1.22176	42
19	.70848	1.41148	.73502	1.36051	.76226	1.31190	.79022	1.26546	.81898	1.22104	41
20	.70891	1.41061	.73547	1 35968	.76272	1.31110	.79070	1.26471	.81946	1.22031	40
21	.70935	1.40974	.73592	1.35885	.76318	1.31031	.79117	1.26395	.81995	1.21959	39
22	.70979	1.40887	.73637	1.35802	.76364	1.30952	.79164	1.26319	.82044	1.21886	38
23	.71023	1.40800	.73681	1.35719	.76410	1.30873	.79212	1.26244	.82092	1.21814	37
24	.71066	1.40714	.73726	1.35637	.76456	1.30795	.79259	1.26169	.82141	1.21742	36
25	.71110	1.40627	.73771	1.35554	.76502	1.30716	.79306	1.26093	.82190	1.21670	35
26	.71154	1.40540	.73816	1.35472	.76548	1.30637	.79354	1.26018	.82238	1.21598	34
27	.71198	1.40454	.73861	1.35389	.76594	1.30558	.79401	1.25943	.82287	1.21526	33
28	.71242	1.40367	.73906	1.35307	.76640	1.30480	.79449	1.25867	.82336	1.21454	32
29	.71285	1.40281	.73951	1.35224	.76686	1.30401	.79496	1.25792	.82385	1.21382	31
30	.71329	1.40195	.73996	1.35142	.76733	1.30323	.79544	1.25717	.82434	1.21310	30
31	.71373	1.40109	.74041	1.35060	.76779	1.30244	.79591	1.25642	.82483	1.21238	29
32	.71417	1.40022	.74086	1.34978	.76825	1.30166	.79639	1.25567	.82531	1.21166	28
33	.71461	1.39936	.74131	1.34896	.76871	1.30087	.79686	1.25492	.82580	1.21094	27
34	.71505	1.39850	.74176	1.34814	.76918	1.30009	.79734	1.25417	.82629	1.21023	26
35	.71549	1.39764	.74221	1.34732	.76964	1.29931	.79781	1.25343	.82678	1.20951	25
36	.71593	1.39679	.74267	1.34650	.77010	1.29853	.79829	1.25268	.82727	1.20879	24
37	.71637	1.39593	.74312	1.34568	.77057	1.29775	.79877	1.25193	.82776	1.20808	23
38	.71681	1.39507	.74357	1.34487	.77103	1.29696	.79924	1.25118	.82825	1.20736	22
39	.71725	1.39421	.74402	1.34405	.77149	1.29618	.79972	1.25044	.82874	1.20665	21
40	.71769	1.39336	.74447	1.34323	.77196	1.29541	.80020	1.24969	.82923	1.20593	20
41	.71813	1.39250	.74492	1.34242	.77242	1.29463	.80067	1.24895	.82972	1.20522	19
42	.71857	1.39165	.74538	1.34160	.77289	1.29385	.80115	1.24820	.83022	1.20451	18
43	.71901	1.39079	.74583	1.34079	.77335	1.29307	.80163	1.24746	.83071	1.20379	17
44	.71946	1.38994	.74628	1.33998	.77382	1.29229	.80211	1.24672	.83120	1.20308	16
45	.71990	1.38909	.74674	1.33916	.77428	1.29152	.80258	1.24597	.83169	1.20237	15
46	.72034	1.38824	.74719	1.33835	.77475	1.29074	.80306	1.24523	.83218	1.20166	14
47	.72078	1.38738	.74764	1.33754	.77521	1.28997	.80354	1.24449	.83268	1.20095	13
48	.72122	1.38653	.74810	1.33673	.77568	1.28919	.80402	1.24375	.83317	1.20024	12
49	.72167	1.38568	.74855	1.33592	.77615	1.28842	.80450	1.24301	.83366	1.19953	11
50	.72211	1.38484	.74900	1.33511	.77661	1.28764	.80498	1.24227	.83415	1.19882	10
51	.72255	1.38399	.74946	1.33430	.77708	1.28687	.80546	1.24153	.83465	1.19811	9
52	.72299	1.38314	.74991	1.33349	.77754	1.28610	.80594	1.24079	.83514	1.19740	8
53	.72344	1.38229	.75037	1.33268	.77801	1.28533	.80642	1.24005	.83564	1.19669	7
54	.72388	1.38145	.75082	1.33187	.77848	1.28456	.80690	1.23931	.83613	1.19599	6
55	.72432	1.38060	.75128	1.33107	.77895	1.28379	.80738	1.23858	.83662	1.19528	5
56	.72477	1.37976	.75173	1.33026	.77941	1.28302	.80786	1.23784	.83712	1.19457	4
57	.72521	1.37891	.75219	1.32946	.77988	1.28225	.80834	1.23710	.83761	1.19387	3
58	.72565	1.37807	.75264	1.32865	.78035	1.28148	.80882	1.23637	.83811	1.19316	2
59	.72610	1.37722	.75310	1.32785	.78082	1.28071	.80930	1.23563	.83860	1.19246	1
60	.72654	1.37638	.75355	1.32704	.78129	1.27994	.80978	1.23490	.83910	1.19175	0
′	Cotang 54°	Tang 54°	Cotang 53°	Tang 53°	Cotang 52°	Tang 52°	Cotang 51°	Tang 51°	Cotang 50°	Tang 50°	′

′	40°		41°		42°		43°		44°		′
	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	
0	.83910	1.19175	.86929	1.15037	.90040	1.11061	.93252	1.07237	.96569	1.03553	60
1	.83960	1.19105	.86980	1.14969	.90093	1.10996	.93306	1.07174	.96625	1.03493	59
2	.84009	1.19035	.87031	1.14902	.90146	1.10931	.93360	1.07112	.96681	1.03433	58
3	.84059	1.18964	.87082	1.14834	.90199	1.10867	.93415	1.07049	.96738	1.03372	57
4	.84108	1.18894	.87133	1.14767	.90251	1.10802	.93469	1.06987	.96794	1.03312	56
5	.84158	1.18824	.87184	1.14699	.90304	1.10737	.93524	1.06925	.96850	1.03252	55
6	.84208	1.18754	.87236	1.14632	.90357	1.10672	.93578	1.06862	.96907	1.03192	54
7	.84258	1.18684	.87287	1.14565	.90410	1.10607	.93633	1.06800	.96963	1.03132	53
8	.84307	1.18614	.87338	1.14498	.90463	1.10543	.93688	1.06738	.97020	1.03072	52
9	.84357	1.18544	.87389	1.14430	.90516	1.10478	.93742	1.06676	.97076	1.03012	51
10	.84407	1.18474	.87441	1.14363	.90569	1.10414	.93797	1.06613	.97133	1.02952	50
11	.84457	1.18404	.87492	1.14296	.90621	1.10349	.93852	1.06551	.97189	1.02892	49
12	.84507	1.18334	.87543	1.14229	.90674	1.10285	.93906	1.06489	.97246	1.02832	48
13	.84556	1.18264	.87595	1.14162	.90727	1.10220	.93961	1.06427	.97302	1.02772	47
14	.84606	1.18194	.87646	1.14095	.90781	1.10156	.94016	1.06365	.97359	1.02713	46
15	.84656	1.18125	.87698	1.14028	.90834	1.10091	.94071	1.06303	.97416	1.02653	45
16	.84706	1.18055	.87749	1.13961	.90887	1.10027	.94125	1.06241	.97472	1.02593	44
17	.84756	1.17986	.87801	1.13894	.90940	1.09963	.94180	1.06179	.07529	1.02533	43
18	.84806	1.17916	.87852	1.13828	.90993	1.09899	.94235	1.06117	.97586	1.02474	42
19	.84856	1.17846	.87904	1.13761	.91046	1.09834	.94290	1.06056	.97643	1.02414	41
20	.84906	1.17777	.87955	1.13694	.91099	1.09770	.94345	1.05994	.97700	1.02355	40
21	.84956	1.17708	.88007	1.13627	.91153	1.09706	.94400	1.05932	.97756	1.02295	39
22	.85006	1.17638	.88059	1.13561	.91206	1.09642	.94455	1.05870	.97813	1.02236	38
23	.85057	1.17569	.88110	1.13494	.91259	1.09578	.94510	1.05809	.97870	1.02176	37
24	.85107	1.17500	.88162	1.13428	.91313	1.09514	.94565	1.05747	.97927	1.02117	36
25	.85157	1.17430	.88214	1.13361	.91366	1.09450	.94620	1.05685	.97984	1.02057	35
26	.85207	1.17361	.88265	1.13295	.91419	1.09386	.94676	1.05624	.98041	1.01998	34
27	.85257	1.17292	.88317	1.13228	.91473	1.09322	.94731	1.05562	.98098	1.01939	33
28	.85308	1.17223	.88369	1.13162	.91526	1.09258	.94786	1.05501	.98155	1.01879	32
29	.85358	1.17154	.88421	1.13096	.91580	1.09195	.94841	1.05439	.98213	1.01820	31
30	.85408	1.17085	.88473	1.13029	.91633	1.09131	.94896	1.05378	.98270	1.01761	30
31	.85458	1.17016	.88524	1.12963	.91687	1.09067	.94952	1.05317	.98327	1.01702	29
32	.85509	1.16947	.88576	1.12897	.91740	1.09003	.95007	1.05255	.98384	1.01642	28
33	.85559	1.16878	.88628	1.12831	.91794	1.08940	.95062	1.05194	.98441	1.01583	27
34	.85609	1.16809	.88680	1.12765	.91847	1.08876	.95118	1.05133	.98499	1.01524	26
35	.85660	1.16741	.88732	1.12699	.91901	1.08813	.95173	1.05072	.98556	1.01465	25
36	.85710	1.16672	.88784	1.12633	.91955	1.08749	.95229	1.05010	.98613	1.01406	24
37	.85761	1.16603	.88836	1.12567	.92008	1.08686	.95284	1.04949	.98671	1.01347	23
38	.85811	1.16535	.88888	1.12501	.92062	1.08622	.95340	1.04888	.98728	1.01288	22
39	.85862	1.16466	.88940	1.12435	.92116	1.08559	.95395	1.04827	.98786	1.01229	21
40	.85912	1.16398	.88992	1.12369	.92170	1.08496	.95451	1.04766	.98843	1.01170	20
41	.85963	1.16329	.89045	1.12303	.92224	1.08432	.95506	1.04705	.98901	1.01112	19
42	.86014	1.16261	.89097	1.12238	.92277	1.08369	.95562	1.04644	.98958	1.01053	18
43	.86064	1.16192	.89149	1.12172	.92331	1.08306	.95618	1.04583	.99016	1.00994	17
44	.86115	1.16124	.89201	1.12106	.92385	1.08243	.95673	1.04522	.99073	1.00935	16
45	.86166	1.16056	.89253	1.12041	.92439	1.08179	.95729	1.04461	.99131	1.00876	15
46	.86216	1.15987	.89306	1.11975	.92493	1.08116	.95785	1.04401	.99189	1.00818	14
47	.86267	1.15919	.89358	1.11909	.92547	1.08053	.95841	1.04340	.99247	1.00759	13
48	.86318	1.15851	.89410	1.11844	.92601	1.07990	.95897	1.04279	.99304	1.00701	12
49	.86368	1.15783	.89463	1.11778	.92655	1.07927	.95952	1.04218	.99362	1.00642	11
50	.86419	1.15715	.89515	1.11713	.92709	1.07864	.96008	1.04158	.99420	1.00583	10
51	.86470	1.15647	.89567	1.11648	.92763	1.07801	.96064	1.04097	.99478	1.00525	9
52	.86521	1.15579	.89620	1.11582	.92817	1.07738	.96120	1.04036	.99536	1.00467	8
53	.86572	1.15511	.89672	1.11517	.92872	1.07676	.96176	1.03976	.99594	1.00408	7
54	.86623	1.15443	.89725	1.11452	.92926	1.07613	.96232	1.03915	.99652	1.00350	6
55	.86674	1.15375	.89777	1.11387	.92980	1.07550	.96288	1.03855	.99710	1.00291	5
56	.86725	1.15308	.89830	1.11321	.93034	1.07487	.96344	1.03794	.99768	1.00233	4
57	.86776	1.15240	.89883	1.11256	.93088	1.07425	.96400	1.03734	.99826	1.00175	3
58	.86827	1.15172	.89935	1.11191	.93143	1.07362	.96457	1.03674	.99884	1.00116	2
59	.86878	1.15104	.89988	1.11126	.93197	1.07299	.96513	1.03613	.99942	1.00058	1
60	.86929	1.15037	.90040	1.11061	.93252	1.07237	.96569	1.03553	1.00000	1.00000	0
′	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	Cotang	Tang	′
	49°		48°		47°		46°		45°		

LOGARITHMIC TABLES.

For detailed directions as to the use of logarithms see page 22.

To Find the Logarithmic Sine, Cosine, Tangent, or Cotangent of an Angle From 0° to 45°.—In the table Logarithms of Trigonometric Functions, find the number of degrees at the top of the page, and the number of minutes in the left-hand column headed ($'$); opposite the latter, and under the proper head, find the desired logarithmic sine, cosine, tangent, or cotangent.

To Find the Logarithmic Sine, Cosine, Tangent, or Cotangent of an Angle From 45° to 90°.—In the table Logarithms of Trigonometric Functions, find the number of degrees at the bottom of the page, and the number of minutes in the right-hand column headed ($'$); opposite the latter, and above the proper head, find the desired logarithmic sine, cosine, tangent, or cotangent.

To Find the Logarithmic Functions for an Angle Containing Degrees, Minutes, and Seconds.—Find the logarithm for the degrees and minutes in the manner given above, then from the column headed "d." take the number next below the logarithm thus found; under the heading "P. P.," find a column headed by this number, and find in this column the number opposite the given number of seconds; add it to the logarithm already found for the degrees and minutes. If the exact number of seconds is not given under "P. P.," the proper values may be found by interpolating between the values given. Since the differences in the column headed "d." represent differences corresponding to 60 seconds, the amount to be added after the logarithm of the degrees and minutes has been found may be obtained by multiplying the difference by the number of seconds and dividing the result by 60.

The columns headed "Cpl. S." and "Cpl. T." on pages 492–494 can be used to find logarithms of angles including seconds less than 3° and greater than 86°. Reduce the degrees, minutes, and seconds to seconds, and use the following formulas, substituting for Cpl. S. and Cpl. T. the values given in the table, and for S. and T., the difference between 10 and Cpl. S. and Cpl. T. as given.

For angles less than 4°, log sin α = log α'' + S.; log tang α = log α'' + T.; log cotg α = Cpl. log α'' + Cpl. T. = Cpl. log tang α; log α'' = log sin α + Cpl. S. = log tang α + Cpl. T. = Cpl. log cotg α + Cpl. T.

For angles greater than 86°, log cos α = log $(90° - \alpha)''$ + S.; log cotg α = log $(90° - \alpha)''$ + T.; log tang α = Cpl. log $(90° - \alpha)''$ + Cpl. T. = Cpl. log cotg α; log $(90° - \alpha)''$ = log cos α + Cpl. S. = log cotg α + Cpl. T. = Cpl. log tang α + Cpl. T.

COMMON LOGARITHMS OF NUMBERS.

No.	Log.	No.	Log.	No.	Log.	No.	Log.	No.	Log.
0	— ∞	**20**	30 103	**40**	60 206	**60**	77 815	**80**	90 309
1	00 000	21	32 222	41	61 278	61	78 533	81	90 849
2	30 103	22	34 242	42	62 325	62	79 239	82	91 381
3	47 712	23	36 173	43	63 347	63	79 934	83	91 908
4	60 206	24	38 021	44	64 345	64	80 618	84	92 428
5	69 897	25	39 794	45	65 321	65	81 291	85	92 942
6	77 815	26	41 497	46	66 276	66	81 954	86	93 450
7	84 510	27	43 136	47	67 210	67	82 607	87	93 952
8	90 309	28	44 716	48	68 124	68	83 251	88	94 448
9	95 424	29	46 240	49	69 020	69	83 885	89	94 939
10	00 000	**30**	47 712	**50**	69 897	**70**	84 510	**90**	95 424
11	04 139	31	49 136	51	70 757	71	85 126	91	95 904
12	07 918	32	50 515	52	71 600	72	85 733	92	96 379
13	11 394	33	51 851	53	72 428	73	86 332	93	96 848
14	14 613	34	53 148	54	73 239	74	86 923	94	97 313
15	17 609	35	54 407	55	74 036	75	87 506	95	97 772
16	20 412	36	55 630	56	74 819	76	88 081	96	98 227
17	23 045	37	56 820	57	75 587	77	88 649	97	98 677
18	25 527	38	57 978	58	76 343	78	89 209	98	99 123
19	27 875	39	59 106	59	77 085	79	89 763	99	99 564
20	30 103	**40**	60 206	**60**	77 815	**80**	90 309	**100**	00 000

N.	L. 0	1	2	3	4	5	6	7	8	9
100	00 000	043	087	130	173	217	260	303	346	389
101	432	475	518	561	604	647	689	732	775	817
102	860	903	945	988	*030	*072	*115	*157	*199	*242
103	01 284	326	368	410	452	494	536	578	620	662
104	703	745	787	828	870	912	953	995	*036	*078
105	02 119	160	202	243	284	325	366	407	449	490
106	531	572	612	653	694	735	776	816	857	898
107	938	979	*019	*060	*100	*141	*181	*222	*262	*302
108	03 342	383	423	463	503	543	583	623	663	703
109	743	782	822	862	902	941	981	*021	*060	*100
110	04 139	179	218	258	297	336	376	415	454	493
111	532	571	610	650	689	727	766	805	844	883
112	922	961	999	*038	*077	*115	*154	*192	*231	*269
113	05 308	346	385	423	461	500	538	576	614	652
114	690	729	767	805	843	881	918	956	994	*032
115	06 070	108	145	183	221	258	296	333	371	408
116	446	483	521	558	595	633	670	707	744	781
117	819	856	893	930	967	*004	*041	*078	*115	*151
118	07 188	225	262	298	335	372	408	445	482	518
119	555	591	628	664	700	737	773	809	846	882
120	918	954	990	*027	*063	*099	*135	*171	*207	*243
121	08 279	314	350	386	422	458	493	529	565	600
122	636	672	707	743	778	814	849	884	920	955
123	991	*026	*061	*096	*132	*167	*202	*237	*272	*307
124	09 342	377	412	447	482	517	552	587	621	656
125	691	726	760	795	830	864	899	934	968	*003
126	10 037	072	106	140	175	209	243	278	312	346
127	380	415	449	483	517	551	585	619	653	687
128	721	755	789	823	857	890	924	958	992	*025
129	11 059	093	126	160	193	227	261	294	327	361
130	394	428	461	494	528	561	594	628	661	694
131	727	760	793	826	860	893	926	959	992	*024
132	12 057	090	123	156	189	222	254	287	320	352
133	385	418	450	483	516	548	581	613	646	678
134	710	743	775	808	840	872	905	937	969	*001
135	13 033	066	098	130	162	194	226	258	290	322
136	354	386	418	450	481	513	545	577	609	640
137	672	704	735	767	799	830	862	893	925	956
138	988	*019	*051	*082	*114	*145	*176	*208	*239	*270
139	14 301	333	364	395	426	457	489	520	551	582
140	613	644	675	706	737	768	799	829	860	891
141	922	953	983	*014	*045	*076	*106	*137	*168	*198
142	15 229	259	290	320	351	381	412	442	473	503
143	534	564	594	625	655	685	715	746	776	806
144	836	866	897	927	957	987	*017	*047	*077	*107
145	16 137	167	197	227	256	286	316	346	376	406
146	435	465	495	524	554	584	613	643	673	702
147	732	761	791	820	850	879	909	938	967	997
148	17 026	056	085	114	143	173	202	231	260	289
149	319	348	377	406	435	464	493	522	551	580
150	609	638	667	696	725	754	782	811	840	869
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	44	**43**	**42**
1	4.4	4.3	4.2
2	8.8	8.6	8.4
3	13.2	12.9	12.6
4	17.6	17.2	16.8
5	22.0	21.5	21.0
6	26.4	25.8	25.2
7	30.8	30.1	29.4
8	35.2	34.4	33.6
9	39.6	38.7	37.8
	41	**40**	**39**
1	4.1	4.0	3.9
2	8.2	8.0	7.8
3	12.3	12.0	11.7
4	16.4	16.0	15.6
5	20.5	20.0	19.5
6	24.6	24.0	23.4
7	28.7	28.0	27.3
8	32.8	32.0	31.2
9	36.9	36.0	35.1
	38	**37**	**36**
1	3.8	3.7	3.6
2	7.6	7.4	7.2
3	11.4	11.1	10.8
4	15.2	14.8	14.4
5	19.0	18.5	18.0
6	22.8	22.2	21.6
7	26.6	25.9	25.2
8	30.4	29.6	28.8
9	34.2	33.3	32.4
	35	**34**	**33**
1	3.5	3.4	3.3
2	7.0	6.8	6.6
3	10.5	10.2	9.9
4	14.0	13.6	13.2
5	17.5	17.0	16.5
6	21.0	20.4	19.8
7	24.5	23.8	23.1
8	28.0	27.2	26.4
9	31.5	30.6	29.7
	32	**31**	**30**
1	3.2	3.1	3.0
2	6.4	6.2	6.0
3	9.6	9.3	9.0
4	12.8	12.4	12.0
5	16.0	15.5	15.0
6	19.2	18.6	18.0
7	22.4	21.7	21.0
8	25.6	24.8	24.0
9	28.8	27.9	27.0

P. P.

N.	L. 0	1	2	3	4	5	6	7	8	9
150	17 609	638	667	696	725	754	782	811	840	869
151	898	926	955	984	*013	*041	*070	*099	*127	*156
152	18 184	213	241	270	298	327	355	384	412	441
153	469	498	526	554	583	611	639	667	696	724
154	752	780	808	837	865	893	921	949	977	*005
155	19 033	061	089	117	145	173	201	229	257	285
156	312	340	368	396	424	451	479	507	535	562
157	590	618	645	673	700	728	756	783	811	838
158	866	893	921	948	976	*003	*030	*058	*085	*112
159	20 140	167	194	222	249	276	303	330	358	385
160	412	439	466	493	520	548	575	602	629	656
161	683	710	737	763	790	817	844	871	898	925
162	952	978	*005	*032	*059	*085	*112	*139	*165	*192
163	21 219	245	272	299	325	352	378	405	431	458
164	484	511	537	564	590	617	643	669	696	722
165	748	775	801	827	854	880	906	932	958	985
166	22 011	037	063	089	115	141	167	194	220	246
167	272	298	324	350	376	401	427	453	479	505
168	531	557	583	608	634	660	686	712	737	763
169	789	814	840	866	891	917	943	968	994	*019
170	23 045	070	096	121	147	172	198	223	249	274
171	300	325	350	376	401	426	452	477	502	528
172	553	578	603	629	654	679	704	729	754	779
173	805	830	855	880	905	930	955	980	*005	*030
174	24 055	080	105	130	155	180	204	229	254	279
175	304	329	353	378	403	428	452	477	502	527
176	551	576	601	625	650	674	699	724	748	773
177	797	822	846	871	895	920	944	969	993	*018
178	25 042	066	091	115	139	164	188	212	237	261
179	285	310	334	358	382	406	431	455	479	503
180	527	551	575	600	624	648	672	696	720	744
181	768	792	816	840	864	888	912	935	959	983
182	26 007	031	055	079	102	126	150	174	198	221
183	245	269	293	316	340	364	387	411	435	458
184	482	505	529	553	576	600	623	647	670	694
185	717	741	764	788	811	834	858	881	905	928
186	951	975	998	*021	*045	*068	*091	*114	*138	*161
187	27 184	207	231	254	277	300	323	346	370	393
188	416	439	462	485	508	531	554	577	600	623
189	646	669	692	715	738	761	784	807	830	852
190	875	898	921	944	967	989	*012	*035	*058	*081
191	28 103	126	149	171	194	217	240	262	285	307
192	330	353	375	398	421	443	466	488	511	533
193	556	578	601	623	646	668	691	713	735	758
194	780	803	825	847	870	892	914	937	959	981
195	29 003	026	048	070	092	115	137	159	181	203
196	226	248	270	292	314	336	358	380	403	425
197	447	469	491	513	535	557	579	601	623	645
198	667	688	710	732	754	776	798	820	842	863
199	885	907	929	951	973	994	*016	*038	*060	*081
200	30 103	125	146	168	190	211	233	255	276	298
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	29	28	27	26	25	24	23	22	21
1	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1
2	5.8	5.6	5.4	5.2	5.0	4.8	4.6	4.4	4.2
3	8.7	8.4	8.1	7.8	7.5	7.2	6.9	6.6	6.3
4	11.6	11.2	10.8	10.4	10.0	9.6	9.2	8.8	8.4
5	14.5	14.0	13.5	13.0	12.5	12.0	11.5	11.0	10.5
6	17.4	16.8	16.2	15.6	15.0	14.4	13.8	13.2	12.6
7	20.3	19.6	18.9	18.2	17.5	16.8	16.1	15.4	14.7
8	23.2	22.4	21.6	20.8	20.0	19.2	18.4	17.6	16.8
9	26.1	25.2	24.3	23.4	22.5	21.6	20.7	19.8	18.9

N.	L. 0	1	2	3	4	5	6	7	8	9
200	30 103	125	146	168	190	211	233	255	276	298
201	320	341	363	384	406	428	449	471	492	514
202	535	557	578	600	621	643	664	685	707	728
203	750	771	792	814	835	856	878	899	920	942
204	963	984	*006	*027	*048	*069	*091	*112	*133	*154
205	31 175	197	218	239	260	281	302	323	345	366
206	387	408	429	450	471	492	513	534	555	576
207	597	618	639	660	681	702	723	744	765	785
208	806	827	848	869	890	911	931	952	973	994
209	32 015	035	056	077	098	118	139	160	181	201
210	222	243	263	284	305	325	346	366	387	408
211	428	449	469	490	510	531	552	572	593	613
212	634	654	675	695	715	736	756	777	797	818
213	838	858	879	899	919	940	960	980	*001	*021
214	33 041	062	082	102	122	143	163	183	203	224
215	244	264	284	304	325	345	365	385	405	425
216	445	465	486	506	526	546	566	586	606	626
217	646	666	686	706	726	746	766	786	806	826
218	846	866	885	905	925	945	965	985	*005	*025
219	34 044	064	084	104	124	143	163	183	203	223
220	242	262	282	301	321	341	361	380	400	420
221	439	459	479	498	518	537	557	577	596	616
222	635	655	674	694	713	733	753	772	792	811
223	830	850	869	889	908	928	947	967	986	*005
224	35 025	044	064	083	102	122	141	160	180	199
225	218	238	257	276	295	315	334	353	372	392
226	411	430	449	468	488	507	526	545	564	583
227	603	622	641	660	679	698	717	736	755	774
228	793	813	832	851	870	889	908	927	946	965
229	984	*003	*021	*040	*059	*078	*097	*116	*135	*154
230	36 173	192	211	229	248	267	286	305	324	342
231	361	380	399	418	436	455	474	493	511	530
232	549	568	586	605	624	642	661	680	698	717
233	736	754	773	791	810	829	847	866	884	903
234	922	940	959	977	996	*014	*033	*051	*070	*088
235	37 107	125	144	162	181	199	218	236	254	273
236	291	310	328	346	365	383	401	420	438	457
237	475	493	511	530	548	566	585	603	621	639
238	658	676	694	712	731	749	767	785	803	822
239	840	858	876	894	912	931	949	967	985	*003
240	38 021	039	057	075	093	112	130	148	166	184
241	202	220	238	256	274	292	310	328	346	364
242	382	399	417	435	453	471	489	507	525	543
243	561	578	596	614	632	650	668	686	703	721
244	739	757	775	792	810	828	846	863	881	899
245	917	934	952	970	987	*005	*023	*041	*058	*076
246	39 094	111	129	146	164	182	199	217	235	252
247	270	287	305	322	340	358	375	393	410	428
248	445	463	480	498	515	533	550	568	585	602
249	620	637	655	672	690	707	724	742	759	777
250	794	811	829	846	863	881	898	915	933	950

| N. | L. 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

P. P.

	22	21
1	2.2	2.1
2	4.4	4.2
3	6.6	6.3
4	8.8	8.4
5	11.0	10.5
6	13.2	12.6
7	15.4	14.7
8	17.6	16.8
9	19.8	18.9

	20
1	2.0
2	4.0
3	6.0
4	8.0
5	10.0
6	12.0
7	14.0
8	16.0
9	18.0

	19
1	1.9
2	3.8
3	5.7
4	7.6
5	9.5
6	11.4
7	13.3
8	15.2
9	17.1

	18
1	1.8
2	3.6
3	5.4
4	7.2
5	9.0
6	10.8
7	12.6
8	14.4
9	16.2

	17
1	1.7
2	3.4
3	5.1
4	6.8
5	8.5
6	10.2
7	11.9
8	13.6
9	15.3

P. P.

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
250	39 794	811	829	846	863	881	898	915	933	950	**18**
251	967	985	*002	*019	*037	*054	*071	*088	*106	*123	1 | 1.8
252	40 140	157	175	192	209	226	243	261	278	295	2 | 3.6
253	312	329	346	364	381	398	415	432	449	466	3 | 5.4
254	483	500	518	535	552	569	586	603	620	637	4 | 7.2
255	654	671	688	705	722	739	756	773	790	807	5 | 9.0
256	824	841	858	875	892	909	926	943	960	976	6 | 10.8
257	993	*010	*027	*044	*061	*078	*095	*111	*128	*145	7 | 12.6
258	41 162	179	196	212	229	246	263	280	296	313	8 | 14.4
259	330	347	363	380	397	414	430	447	464	481	9 | 16.2
260	497	514	531	547	564	581	597	614	631	647	**17**
261	664	681	697	714	731	747	764	780	797	814	1 | 1.7
262	830	847	863	880	896	913	929	946	963	979	2 | 3.4
263	996	*012	*029	*045	*062	*078	*095	*111	*127	*144	3 | 5.1
264	42 160	177	193	210	226	243	259	275	292	308	4 | 6.8
265	325	341	357	374	390	406	423	439	455	472	5 | 8.5
266	488	504	521	537	553	570	586	602	619	635	6 | 10.2
267	651	667	684	700	716	732	749	765	781	797	7 | 11.9
268	813	830	846	862	878	894	911	927	943	959	8 | 13.6
269	975	991	*008	*024	*040	*056	*072	*088	*104	*120	9 | 15.3
270	43 136	152	169	185	201	217	233	249	265	281	**16**
271	297	313	329	345	361	377	393	409	425	441	1 | 1.6
272	457	473	489	505	521	537	553	569	584	600	2 | 3.2
273	616	632	648	664	680	696	712	727	743	759	3 | 4.8
274	775	791	807	823	838	854	870	886	902	917	4 | 6.4
275	933	949	965	981	996	*012	*028	*044	*059	*075	5 | 8.0
276	44 091	107	122	138	154	170	185	201	217	232	6 | 9.6
277	248	264	279	295	311	326	342	358	373	389	7 | 11.2
278	404	420	436	451	467	483	498	514	529	545	8 | 12.8
279	560	576	592	607	623	638	654	669	685	700	9 | 14.4
280	716	731	747	762	778	793	809	824	840	855	**15**
281	871	886	902	917	932	948	963	979	994	*010	1 | 1.5
282	45 025	040	056	071	086	102	117	133	148	163	2 | 3.0
283	179	194	209	225	240	255	271	286	301	317	3 | 4.5
284	332	347	362	378	393	408	423	439	454	469	4 | 6.0
285	484	500	515	530	545	561	576	591	606	621	5 | 7.5
286	637	652	667	682	697	712	728	743	758	773	6 | 9.0
287	788	803	818	834	849	864	879	894	909	924	7 | 10.5
288	939	954	969	984	*000	*015	*030	*045	*060	*075	8 | 12.0
289	46 090	105	120	135	150	165	180	195	210	225	9 | 13.5
290	240	255	270	285	300	315	330	345	359	374	**14**
291	389	404	419	434	449	464	479	494	509	523	1 | 1.4
292	538	553	568	583	598	613	627	642	657	672	2 | 2.8
293	687	702	716	731	746	761	776	790	805	820	3 | 4.2
294	835	850	864	879	894	909	923	938	953	967	4 | 5.6
295	982	997	*012	*026	*041	*056	*070	*085	*100	*114	5 | 7.0
296	47 129	144	159	173	188	202	217	232	246	261	6 | 8.4
297	276	290	305	319	334	349	363	378	392	407	7 | 9.8
298	422	436	451	465	480	494	509	524	538	553	8 | 11.2
299	567	582	596	611	625	640	654	669	683	698	9 | 12.6
300	712	727	741	756	770	784	799	813	828	842	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

N.	L. 0	1	2	3	4	5	6	7	8	9
300	47 712	727	741	756	770	784	799	813	828	842
301	857	871	885	900	914	929	943	958	972	986
302	48 001	015	029	044	058	073	087	101	116	130
303	144	159	173	187	202	216	230	244	259	273
304	287	302	316	330	344	359	373	387	401	416
305	430	444	458	473	487	501	515	530	544	558
306	572	586	601	615	629	643	657	671	686	700
307	714	728	742	756	770	785	799	813	827	841
308	855	869	883	897	911	926	940	954	968	982
309	996	*010	*024	*038	*052	*066	*080	*094	*108	*122
310	49 136	150	164	178	192	206	220	234	248	262
311	276	290	304	318	332	346	360	374	388	402
312	415	429	443	457	471	485	499	513	527	541
313	554	568	582	596	610	624	638	651	665	679
314	693	707	721	734	748	762	776	790	803	817
315	831	845	859	872	886	900	914	927	941	955
316	969	982	996	*010	*024	*037	*051	*065	*079	*092
317	50 106	120	133	147	161	174	188	202	215	229
318	243	256	270	284	297	311	325	338	352	365
319	379	393	406	420	433	447	461	474	488	501
320	515	529	542	556	569	583	596	610	623	637
321	651	664	678	691	705	718	732	745	759	772
322	786	799	813	826	840	853	866	880	893	907
323	920	934	947	961	974	987	*001	*014	*028	*041
324	51 055	068	081	095	108	121	135	148	162	175
325	188	202	215	228	242	255	268	282	295	308
326	322	335	348	362	375	388	402	415	428	441
327	455	468	481	495	508	521	534	548	561	574
328	587	601	614	627	640	654	667	680	693	706
329	720	733	746	759	772	786	799	812	825	838
330	851	865	878	891	904	917	930	943	957	970
331	983	996	*009	*022	*035	*048	*061	*075	*088	*101
332	52 114	127	140	153	166	179	192	205	218	231
333	244	257	270	284	297	310	323	336	349	362
334	375	388	401	414	427	440	453	466	479	492
335	504	517	530	543	556	569	582	595	608	621
336	634	647	660	673	686	699	711	724	737	750
337	763	776	789	802	815	827	840	853	866	879
338	892	905	917	930	943	956	969	982	994	*007
339	53 020	033	046	058	071	084	097	110	122	135
340	148	161	173	186	199	212	224	237	250	263
341	275	288	301	314	326	339	352	364	377	390
342	403	415	428	441	453	466	479	491	504	517
343	529	542	555	567	580	593	605	618	631	643
344	656	668	681	694	706	719	732	744	757	769
345	782	794	807	820	832	845	857	870	882	895
346	908	920	933	945	958	970	983	995	*008	*020
347	54 033	045	058	070	083	095	108	120	133	145
348	158	170	183	195	208	220	233	245	258	270
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352	654	667	679	691	704	716	728	741	753	765
353	777	790	802	814	827	839	851	864	876	888
354	900	913	925	937	949	962	974	986	998	*011
355	55 023	035	047	060	072	084	096	108	121	133
356	145	157	169	182	194	206	218	230	242	255
357	267	279	291	303	315	328	340	352	364	376
358	388	400	413	425	437	449	461	473	485	497
359	509	522	534	546	558	570	582	594	606	618
360	630	642	654	666	678	691	703	715	727	739
361	751	763	775	787	799	811	823	835	847	859
362	871	883	895	907	919	931	943	955	967	979
363	991	*003	*015	*027	*038	*050	*062	*074	*086	*098
364	56 110	122	134	146	158	170	182	194	205	217
365	229	241	253	265	277	289	301	312	324	336
366	348	360	372	384	396	407	419	431	443	455
367	467	478	490	502	514	526	538	549	561	573
368	585	597	608	620	632	644	656	667	679	691
369	703	714	726	738	750	761	773	785	797	808
370	820	832	844	855	867	879	891	902	914	926
371	937	949	961	972	984	996	*008	*019	*031	*043
372	57 054	066	078	089	101	113	124	136	148	159
373	171	183	194	206	217	229	241	252	264	276
374	287	299	310	322	334	345	357	368	380	392
375	403	415	426	438	449	461	473	484	496	507
376	519	530	542	553	565	576	588	600	611	623
377	634	646	657	669	680	692	703	715	726	738
378	749	761	772	784	795	807	818	830	841	852
379	864	875	887	898	910	921	933	944	955	967
380	978	990	*001	*013	*024	*035	*047	*058	*070	*081
381	58 092	104	115	127	138	149	161	172	184	195
382	206	218	229	240	252	263	274	286	297	309
383	320	331	343	354	365	377	388	399	410	422
384	433	444	456	467	478	490	501	512	524	535
385	546	557	569	580	591	602	614	625	636	647
386	659	670	681	692	704	715	726	737	749	760
387	771	782	794	805	816	827	838	850	861	872
388	883	894	906	917	928	939	950	961	973	984
389	995	*006	*017	*028	*040	*051	*062	*073	*084	*095
390	59 106	118	129	140	151	162	173	184	195	207
391	218	229	240	251	262	273	284	295	306	318
392	329	340	351	362	373	384	395	406	417	428
393	439	450	461	472	483	494	506	517	528	539
394	550	561	572	583	594	605	616	627	638	649
395	660	671	682	693	704	715	726	737	748	759
396	770	780	791	802	813	824	835	846	857	868
397	879	890	901	912	923	934	945	956	966	977
398	988	999	*010	*021	*032	*043	*054	*065	*076	*086
399	60 097	108	119	130	141	152	163	173	184	195
400	206	217	228	239	249	260	271	282	293	304
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402	423	433	444	455	466	477	487	498	509	520
403	531	541	552	563	574	584	595	606	617	627
404	638	649	660	670	681	692	703	713	724	735
405	746	756	767	778	788	799	810	821	831	842
406	853	863	874	885	895	906	917	927	938	949
407	959	970	981	991	*002	*013	*023	*034	*045	*055
408	61 066	077	087	098	109	119	130	140	151	162
409	172	183	194	204	215	225	236	247	257	268
410	278	289	300	310	321	331	342	352	363	374
411	384	395	405	416	426	437	448	458	469	479
412	490	500	511	521	532	542	553	563	574	584
413	595	606	616	627	637	648	658	669	679	690
414	700	711	721	731	742	752	763	773	784	794
415	805	815	826	836	847	857	868	878	888	899
416	909	920	930	941	951	962	972	982	993	*003
417	62 014	024	034	045	055	066	076	086	097	107
418	118	128	138	149	159	170	180	190	201	211
419	221	232	242	252	263	273	284	294	304	315
420	325	335	346	356	366	377	387	397	408	418
421	428	439	449	459	469	480	490	500	511	521
422	531	542	552	562	572	583	593	603	613	624
423	634	644	655	665	675	685	696	706	716	726
424	737	747	757	767	778	788	798	808	818	829
425	839	849	859	870	880	890	900	910	921	931
426	941	951	961	972	982	992	*002	*012	*022	*033
427	63 043	053	063	073	083	094	104	114	124	134
428	144	155	165	175	185	195	205	215	225	236
429	246	256	266	276	286	296	306	317	327	337
430	347	357	367	377	387	397	407	417	428	438
431	448	458	468	478	488	498	508	518	528	538
432	548	558	568	579	589	599	609	619	629	639
433	649	659	669	679	689	699	709	719	729	739
434	749	759	769	779	789	799	809	819	829	839
435	849	859	869	879	889	899	909	919	929	939
436	949	959	969	979	988	998	*008	*018	*028	*038
437	64 048	058	068	078	088	098	108	118	128	137
438	147	157	167	177	187	197	207	217	227	237
439	246	256	266	276	286	296	306	316	326	335
440	345	355	365	375	385	395	404	414	424	434
441	444	454	464	473	483	493	503	513	523	532
442	542	552	562	572	582	591	601	611	621	631
443	640	650	660	670	680	689	699	709	719	729
444	738	748	758	768	777	787	797	807	816	826
445	836	846	856	865	875	885	895	904	914	924
446	933	943	953	963	972	982	992	*002	*011	*021
447	65 031	040	050	060	070	079	089	099	108	118
448	128	137	147	157	167	176	186	196	205	215
449	225	234	244	254	263	273	283	292	302	312
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452	514	523	533	543	552	562	571	581	591	600
453	610	619	629	639	648	658	667	677	686	696
454	706	715	725	734	744	753	763	772	782	792
455	801	811	820	830	839	849	858	868	877	887
456	896	906	916	925	935	944	954	963	973	982
457	992	*001	*011	*020	*030	*039	*049	*058	*068	*077
458	66 087	096	106	115	124	134	143	153	162	172
459	181	191	200	210	219	229	238	247	257	266
460	276	285	295	304	314	323	332	342	351	361
461	370	380	389	398	408	417	427	436	445	455
462	464	474	483	492	502	511	521	530	539	549
463	558	567	577	586	596	605	614	624	633	642
464	652	661	671	680	689	699	708	717	727	736
465	745	755	764	773	783	792	801	811	820	829
466	839	848	857	867	876	885	894	904	913	922
467	932	941	950	960	969	978	987	997	*006	*015
468	67 025	034	043	052	062	071	080	089	099	108
469	117	127	136	145	154	164	173	182	191	201
470	210	219	228	237	247	256	265	274	284	293
471	302	311	321	330	339	348	357	367	376	385
472	394	403	413	422	431	440	449	459	468	477
473	486	495	504	514	523	532	541	550	560	569
474	578	587	596	605	614	624	633	642	651	660
475	669	679	688	697	706	715	724	733	742	752
476	761	770	779	788	797	806	815	825	834	843
477	852	861	870	879	888	897	906	916	925	934
478	943	952	961	970	979	988	997	*006	*015	*024
479	68 034	043	052	061	070	079	088	097	106	115
480	124	133	142	151	160	169	178	187	196	205
481	215	224	233	242	251	260	269	278	287	296
482	305	314	323	332	341	350	359	368	377	386
483	395	404	413	422	431	440	449	458	467	476
484	485	494	502	511	520	529	538	547	556	565
485	574	583	592	601	610	619	628	637	646	655
486	664	673	681	690	699	708	717	726	735	744
487	753	762	771	780	789	797	806	815	824	833
488	842	851	860	869	878	886	895	904	913	922
489	931	940	949	958	966	975	984	993	*002	*011
490	69 020	028	037	046	055	064	073	082	090	099
491	108	117	126	135	144	152	161	170	179	188
492	197	205	214	223	232	241	249	258	267	276
493	285	294	302	311	320	329	338	346	355	364
494	373	381	390	399	408	417	425	434	443	452
495	461	469	478	487	496	504	513	522	531	539
496	548	557	566	574	583	592	601	609	618	627
497	636	644	653	662	671	679	688	697	705	714
498	723	732	740	749	758	767	775	784	793	801
499	810	819	827	836	845	854	862	871	880	888
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501	984	992	*001	*010	*018	*027	*036	*044	*053	*062
502	70 070	079	088	096	105	114	122	131	140	148
503	157	165	174	183	191	200	209	217	226	234
504	243	252	260	269	278	286	295	303	312	321
505	329	338	346	355	364	372	381	389	398	406
506	415	424	432	441	449	458	467	475	484	492
507	501	509	518	526	535	544	552	561	569	578
508	586	595	603	612	621	629	638	646	655	663
509	672	680	689	697	706	714	723	731	740	749
510	757	766	774	783	791	800	808	817	825	834
511	842	851	859	868	876	885	893	902	910	919
512	927	935	944	952	961	969	978	986	995	*003
513	71 012	020	029	037	046	054	063	071	079	088
514	096	105	113	122	130	139	147	155	164	172
515	181	189	198	206	214	223	231	240	248	257
516	265	273	282	290	299	307	315	324	332	341
517	349	357	366	374	383	391	399	408	416	425
518	433	441	450	458	466	475	483	492	500	508
519	517	525	533	542	550	559	567	575	584	592
520	600	609	617	625	634	642	650	659	667	675
521	684	692	700	709	717	725	734	742	750	759
522	767	775	784	792	800	809	817	825	834	842
523	850	858	867	875	883	892	900	908	917	925
524	933	941	950	958	966	975	983	991	999	*008
525	72 016	024	032	041	049	057	066	074	082	090
526	099	107	115	123	132	140	148	156	165	173
527	181	189	198	206	214	222	230	239	247	255
528	263	272	280	288	296	304	313	321	329	337
529	346	354	362	370	378	387	395	403	411	419
530	428	436	444	452	460	469	477	485	493	501
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532	591	599	607	616	624	632	640	648	656	665
533	673	681	689	697	705	713	722	730	738	746
534	754	762	770	779	787	795	803	811	819	827
535	835	843	852	860	868	876	884	892	900	908
536	916	925	933	941	949	957	965	973	981	989
537	997	*006	*014	*022	*030	*038	*046	*054	*062	*070
538	73 078	086	094	102	111	119	127	135	143	151
539	159	167	175	183	191	199	207	215	223	231
540	239	247	255	263	272	280	288	296	304	312
541	320	328	336	344	352	360	368	376	384	392
542	400	408	416	424	432	440	448	456	464	472
543	480	488	496	504	512	520	528	536	544	552
544	560	568	576	584	592	600	608	616	624	632
545	640	648	656	664	672	679	687	695	703	711
546	719	727	735	743	751	759	767	775	783	791
547	799	807	815	823	830	838	846	854	862	870
548	878	886	894	902	910	918	926	933	941	949
549	957	965	973	981	989	997	*005	*013	*020	*028
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P. P.

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552	194	202	210	218	225	233	241	249	257	265
553	273	280	288	296	304	312	320	327	335	343
554	351	359	367	374	382	390	398	406	414	421
555	429	437	445	453	461	468	476	484	492	500
556	507	515	523	531	539	547	554	562	570	578
557	586	593	601	609	617	624	632	640	648	656
558	663	671	679	687	695	702	710	718	726	733
559	741	749	757	764	772	780	788	796	803	811
560	819	827	834	842	850	858	865	873	881	889
561	896	904	912	920	927	935	943	950	958	966
562	974	981	989	997	*005	*012	*020	*028	*035	*043
563	75 051	059	066	074	082	089	097	105	113	120
564	128	136	143	151	159	166	174	182	189	197
565	205	213	220	228	236	243	251	259	266	274
566	282	289	297	305	312	320	328	335	343	351
567	358	366	374	381	389	397	404	412	420	427
568	435	442	450	458	465	473	481	488	496	504
569	511	519	526	534	542	549	557	565	572	580
570	587	595	603	610	618	626	633	641	648	656
571	664	671	679	686	694	702	709	717	724	732
572	740	747	755	762	770	778	785	793	800	808
573	815	823	831	838	846	853	861	868	876	884
574	891	899	906	914	921	929	937	944	952	959
575	967	974	982	989	997	*005	*012	*020	*027	*035
576	76 042	050	057	065	072	080	087	095	103	110
577	118	125	133	140	148	155	163	170	178	185
578	193	200	208	215	223	230	238	245	253	260
579	268	275	283	290	298	305	313	320	328	335
580	343	350	358	365	373	380	388	395	403	410
581	418	425	433	440	448	455	462	470	477	485
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584	641	649	656	664	671	678	686	693	701	708
585	716	723	730	738	745	753	760	768	775	782
586	790	797	805	812	819	827	834	842	849	856
587	864	871	879	886	893	901	908	916	923	930
588	938	945	953	960	967	975	982	989	997	*004
589	77 012	019	026	034	041	048	056	063	070	078
590	085	093	100	107	115	122	129	137	144	151
591	159	166	173	181	188	195	203	210	217	225
592	232	240	247	254	262	269	276	283	291	298
593	305	313	320	327	335	342	349	357	364	371
594	379	386	393	401	408	415	422	430	437	444
595	452	459	466	474	481	488	495	503	510	517
596	525	532	539	546	554	561	568	576	583	590
597	597	605	612	619	627	634	641	648	656	663
598	670	677	685	692	699	706	714	721	728	735
599	743	750	757	764	772	779	786	793	801	808
600	815	822	830	837	844	851	859	866	873	880
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P. P.

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P P.

N.	L. 0	1	2	3	4	5	6	7	8	9
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601	887	895	902	909	916	924	931	938	945	952
602	960	967	974	981	988	996	*003	*010	*017	*025
603	78 032	039	046	053	061	068	075	082	089	097
604	104	111	118	125	132	140	147	154	161	168
605	176	183	190	197	204	211	219	226	233	240
606	247	254	262	269	276	283	290	297	305	312
607	319	326	333	340	347	355	362	369	376	383
608	390	398	405	412	419	426	433	440	447	455
609	462	469	476	483	490	497	504	512	519	526
610	533	540	547	554	561	569	576	583	590	597
611	604	611	618	625	633	640	647	654	661	668
612	675	682	689	696	704	711	718	725	732	739
613	746	753	760	767	774	781	789	796	803	810
614	817	824	831	838	845	852	859	866	873	880
615	888	895	902	909	916	923	930	937	944	951
616	958	965	972	979	986	993	*000	*007	*014	*021
617	79 029	036	043	050	057	064	071	078	085	092
618	099	106	113	120	127	134	141	148	155	162
619	169	176	183	190	197	204	211	218	225	232
620	239	246	253	260	267	274	281	288	295	302
621	309	316	323	330	337	344	351	358	365	372
622	379	386	393	400	407	414	421	428	435	442
623	449	456	463	470	477	484	491	498	505	511
624	518	525	532	539	546	553	560	567	574	581
625	588	595	602	609	616	623	630	637	644	650
626	657	664	671	678	685	692	699	706	713	720
627	727	734	741	748	754	761	768	775	782	789
628	796	803	810	817	824	831	837	844	851	858
629	865	872	879	886	893	900	906	913	920	927
630	934	941	948	955	962	969	975	982	989	996
631	80 003	010	017	024	030	037	044	051	058	065
632	072	079	085	092	099	106	113	120	127	134
633	140	147	154	161	168	175	182	188	195	202
634	209	216	223	229	236	243	250	257	264	271
635	277	284	291	298	305	312	318	325	332	339
636	346	353	359	366	373	380	387	393	400	407
637	414	421	428	434	441	448	455	462	468	475
638	482	489	496	502	509	516	523	530	536	543
639	550	557	564	570	577	584	591	598	604	611
640	618	625	632	638	645	652	659	665	672	679
641	686	693	699	706	713	720	726	733	740	747
642	754	760	767	774	781	787	794	801	808	814
643	821	828	835	841	848	855	862	868	875	882
644	889	895	902	909	916	922	929	936	943	949
645	956	963	969	976	983	990	996	*003	*010	*017
646	81 023	030	037	043	050	057	064	070	077	084
647	090	097	104	111	117	124	131	137	144	151
648	158	164	171	178	184	191	198	204	211	218
649	224	231	238	245	251	258	265	271	278	285
650	291	298	305	311	318	325	331	338	345	351
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P. P.

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651	358	365	371	378	385	391	398	405	411	418	
652	425	431	438	445	451	458	465	471	478	485	
653	491	498	505	511	518	525	531	538	544	551	
654	558	564	571	578	584	591	598	604	611	617	
655	624	631	637	644	651	657	664	671	677	684	
656	690	697	704	710	717	723	730	737	743	750	
657	757	763	770	776	783	790	796	803	809	816	
658	823	829	836	842	849	856	862	869	875	882	
659	889	895	902	908	915	921	928	935	941	948	
660	954	961	968	974	981	987	994	*000	*007	*014	**7**
661	82 020	027	033	040	046	053	060	066	073	079	1 0.7
662	086	092	099	105	112	119	125	132	138	145	2 1.4
663	151	158	164	171	178	184	191	197	204	210	3 2.1
664	217	223	230	236	243	249	256	263	269	276	4 2.8
665	282	289	295	302	308	315	321	328	334	341	5 3.5
666	347	354	360	367	373	380	387	393	400	406	6 4.2
667	413	419	426	432	439	445	452	458	465	471	7 4.9
668	478	484	491	497	504	510	517	523	530	536	8 5.6
669	543	549	556	562	569	575	582	588	595	601	9 6.3
670	607	614	620	627	633	640	646	653	659	666	
671	672	679	685	692	698	705	711	718	724	730	
672	737	743	750	756	763	769	776	782	789	795	
673	802	808	814	821	827	834	840	847	853	860	
674	866	872	879	885	892	898	905	911	918	924	
675	930	937	943	950	956	963	969	975	982	988	
676	995	*001	*008	*014	*020	*027	*033	*040	*046	*052	
677	83 059	065	072	078	085	091	097	104	110	117	
678	123	129	136	142	149	155	161	168	174	181	
679	187	193	200	206	213	219	225	232	238	245	
680	251	257	264	270	276	283	289	296	302	308	**6**
681	315	321	327	334	340	347	353	359	366	372	1 0.6
682	378	385	391	398	404	410	417	423	429	436	2 1.2
683	442	448	455	461	467	474	480	487	493	499	3 1.8
684	506	512	518	525	531	537	544	550	556	563	4 2.4
685	569	575	582	588	594	601	607	613	620	626	5 3.0
686	632	639	645	651	658	664	670	677	683	689	6 3.6
687	696	702	708	715	721	727	734	740	746	753	7 4.2
688	759	765	771	778	784	790	797	803	809	816	8 4.8
689	822	828	835	841	847	853	860	866	872	879	9 5.4
690	885	891	897	904	910	916	923	929	935	942	
691	948	954	960	967	973	979	985	992	998	*004	
692	84 011	017	023	029	036	042	048	055	061	067	
693	073	080	086	092	098	105	111	117	123	130	
694	136	142	148	155	161	167	173	180	186	192	
695	198	205	211	217	223	230	236	242	248	255	
696	261	267	273	280	286	292	298	305	311	317	
697	323	330	336	342	348	354	361	367	373	379	
698	386	392	398	404	410	417	423	429	435	442	
699	448	454	460	466	473	479	485	491	497	504	
700	510	516	522	528	535	541	547	553	559	566	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

N.	L. 0	1	2	3	4	5	6	7	8	9
700	84 510	516	522	528	535	541	547	553	559	566
701	572	578	584	590	597	603	609	615	621	628
702	634	640	646	652	658	665	671	677	683	689
703	696	702	708	714	720	726	733	739	745	751
704	757	763	770	776	782	788	794	800	807	813
705	819	825	831	837	844	850	856	862	868	874
706	880	887	893	899	905	911	917	924	930	936
707	942	948	954	960	967	973	979	985	991	997
708	85 003	009	016	022	028	034	040	046	052	058
709	065	071	077	083	089	095	101	107	114	120
710	126	132	138	144	150	156	163	169	175	181
711	187	193	199	205	211	217	224	230	236	242
712	248	254	260	266	272	278	285	291	297	303
713	309	315	321	327	333	339	345	352	358	364
714	370	376	382	388	394	400	406	412	418	425
715	431	437	443	449	455	461	467	473	479	485
716	491	497	503	509	516	522	528	534	540	546
717	552	558	564	570	576	582	588	594	600	606
718	612	618	625	631	637	643	649	655	661	667
719	673	679	685	691	697	703	709	715	721	727
720	733	739	745	751	757	763	769	775	781	788
721	794	800	806	812	818	824	830	836	842	848
722	854	860	866	872	878	884	890	896	902	908
723	914	920	926	932	938	944	950	956	962	968
724	974	980	986	992	998	*004	*010	*016	*022	*028
725	86 034	040	046	052	058	064	070	076	082	088
726	094	100	106	112	118	124	130	136	141	147
727	153	159	165	171	177	183	189	195	201	207
728	213	219	225	231	237	243	249	255	261	267
729	273	279	285	291	297	303	308	314	320	326
730	332	338	344	350	356	362	368	374	380	386
731	392	398	404	410	415	421	427	433	439	445
732	451	457	463	469	475	481	487	493	499	504
733	510	516	522	528	534	540	546	552	558	564
734	570	576	581	587	593	599	605	611	617	623
735	629	635	641	646	652	658	664	670	676	682
736	688	694	700	705	711	717	723	729	735	741
737	747	753	759	764	770	776	782	788	794	800
738	806	812	817	823	829	835	841	847	853	859
739	864	870	876	882	888	894	900	906	911	917
740	923	929	935	941	947	953	958	964	970	976
741	982	988	994	999	*005	*011	*017	*023	*029	*035
742	87 040	046	052	058	064	070	075	081	087	093
743	099	105	111	116	122	128	134	140	146	151
744	157	163	169	175	181	186	192	198	204	210
745	216	221	227	233	239	245	251	256	262	268
746	274	280	286	291	297	303	309	315	320	326
747	332	338	344	349	355	361	367	373	379	384
748	390	396	402	408	413	419	425	431	437	442
749	448	454	460	466	471	477	483	489	495	500
750	506	512	518	523	529	535	541	547	552	558
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

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9	4 5

P. P.

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
750	87 506	512	518	523	529	535	541	547	552	558	
751	564	570	576	581	587	593	599	604	610	616	
752	622	628	633	639	645	651	656	662	668	674	
753	679	685	691	697	703	708	714	720	726	731	
754	737	743	749	754	760	766	772	777	783	789	
755	795	800	806	812	818	823	829	835	841	846	
756	852	858	864	869	875	881	887	892	898	904	
757	910	915	921	927	933	938	944	950	955	961	
758	967	973	978	984	990	996	*001	*007	*013	*018	
759	88 024	030	036	041	047	053	058	064	070	076	
760	081	087	093	098	104	110	116	121	127	133	**6**
761	138	144	150	156	161	167	173	178	184	190	1 | 0.6
762	195	201	207	213	218	224	230	235	241	247	2 | 1.2
763	252	258	264	270	275	281	287	292	298	304	3 | 1.8
764	309	315	321	326	332	338	343	349	355	360	4 | 2.4
765	366	372	377	383	389	395	400	406	412	417	5 | 3.0
766	423	429	434	440	446	451	457	463	468	474	6 | 3.6
767	480	485	491	497	502	508	513	519	525	530	7 | 4.2
768	536	542	547	553	559	564	570	576	581	587	8 | 4.8
769	593	598	604	610	615	621	627	632	638	643	9 | 5.4
770	649	655	660	666	672	677	683	689	694	700	
771	705	711	717	722	728	734	739	745	750	756	
772	762	767	773	779	784	790	795	801	807	812	
773	818	824	829	835	840	846	852	857	863	868	
774	874	880	885	891	897	902	908	913	919	925	
775	930	936	941	947	953	958	964	969	975	981	
776	986	992	997	*003	*009	*014	*020	*025	*031	*037	
777	89 042	048	053	059	064	070	076	081	087	092	
778	098	104	109	115	120	126	131	137	143	148	
779	154	159	165	170	176	182	187	193	198	204	
780	209	215	221	226	232	237	243	248	254	260	**5**
781	265	271	276	282	287	293	298	304	310	315	1 | 0.5
782	321	326	332	337	343	348	354	360	365	371	2 | 1.0
783	376	382	387	393	398	404	409	415	421	426	3 | 1.5
784	432	437	443	448	454	459	465	470	476	481	4 | 2.0
785	487	492	498	504	509	515	520	526	531	537	5 | 2.5
786	542	548	553	559	564	570	575	581	586	592	6 | 3.0
787	597	603	609	614	620	625	631	636	642	647	7 | 3.5
788	653	658	664	669	675	680	686	691	697	702	8 | 4.0
789	708	713	719	724	730	735	741	746	752	757	9 | 4.5
790	763	768	774	779	785	790	796	801	807	812	
791	818	823	829	834	840	845	851	856	862	867	
792	873	878	883	889	894	900	905	911	916	922	
793	927	933	938	944	949	955	960	966	971	977	
794	982	988	993	998	*004	*009	*015	*020	*026	*031	
795	90 037	042	048	053	059	064	069	075	080	086	
796	091	097	102	108	113	119	124	129	135	140	
797	146	151	157	162	168	173	179	184	189	195	
798	200	206	211	217	222	227	233	238	244	249	
799	255	260	266	271	276	282	287	293	298	304	
800	309	314	320	325	331	336	342	347	352	358	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
800	90 309	314	320	325	331	336	342	347	352	358	
801	363	369	374	380	385	390	396	401	407	412	
802	417	423	428	434	439	445	450	455	461	466	
803	472	477	482	488	493	499	504	509	515	520	
804	526	531	536	542	547	553	558	563	569	574	
805	580	585	590	596	601	607	612	617	623	628	
806	634	639	644	650	655	660	666	671	677	682	
807	687	693	698	703	709	714	720	725	730	736	
808	741	747	752	757	763	768	773	779	784	789	
809	795	800	806	811	816	822	827	832	838	843	
810	849	854	859	865	870	875	881	886	891	897	6
811	902	907	913	918	924	929	934	940	945	950	
812	956	961	966	972	977	982	988	993	998	*004	1 0.6
813	91 009	014	020	025	030	036	041	046	052	057	2 1.2
814	062	068	073	078	084	089	094	100	105	110	3 1.8
815	116	121	126	132	137	142	148	153	158	164	4 2.4
816	169	174	180	185	190	196	201	206	212	217	5 3.0
817	222	228	233	238	243	249	254	259	265	270	6 3.6
818	275	281	286	291	297	302	307	312	318	323	7 4.2
819	328	334	339	344	350	355	360	365	371	376	8 4.8 9 5.4
820	381	387	392	397	403	408	413	418	424	429	
821	434	440	445	450	455	461	466	471	477	482	
822	487	492	498	503	508	514	519	524	529	535	
823	540	545	551	556	561	566	572	577	582	587	
824	593	598	603	609	614	619	624	630	635	640	
825	645	651	656	661	666	672	677	682	687	693	
826	698	703	709	714	719	724	730	735	740	745	
827	751	756	761	766	772	777	782	787	793	798	
828	803	808	814	819	824	829	834	840	845	850	
829	855	861	866	871	876	882	887	892	897	903	
830	908	913	918	924	929	934	939	944	950	955	5
831	960	965	971	976	981	986	991	997	*002	*007	1 0.5
832	92 012	018	023	028	033	038	044	049	054	059	2 1.0
833	065	070	075	080	085	091	096	101	106	111	3 1.5
834	117	122	127	132	137	143	148	153	158	163	4 2.0
835	169	174	179	184	189	195	200	205	210	215	5 2.5
836	221	226	231	236	241	247	252	257	262	267	6 3.0
837	273	278	283	288	293	298	304	309	314	319	7 3.5
838	324	330	335	340	345	350	355	361	366	371	8 4.0
839	376	381	387	392	397	402	407	412	418	423	9 4.5
840	428	433	438	443	449	454	459	464	469	474	
841	480	485	490	495	500	505	511	516	521	526	
842	531	536	542	547	552	557	562	567	572	578	
843	583	588	593	598	603	609	614	619	624	629	
844	634	639	645	650	655	660	665	670	675	681	
845	586	691	696	701	706	711	716	722	727	732	
846	737	742	747	752	758	763	768	773	778	783	
847	788	793	799	804	809	814	819	824	829	834	
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849	891	896	901	906	911	916	921	927	932	937	
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N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

N.	L. 0	1	2	3	4	5	6	7	8	9
850	92 942	947	952	957	962	967	973	978	983	988
851	993	998	*003	*008	*013	*018	*024	*029	*034	*039
852	93 044	049	054	059	064	069	075	080	085	090
853	095	100	105	110	115	120	125	131	136	141
854	146	151	156	161	166	171	176	181	186	192
855	197	202	207	212	217	222	227	232	237	242
856	247	252	258	263	268	273	278	283	288	293
857	298	303	308	313	318	323	328	334	339	344
858	349	354	359	364	369	374	379	384	389	394
859	399	404	409	414	420	425	430	435	440	445
860	450	455	460	465	470	475	480	485	490	495
861	500	505	510	515	520	526	531	536	541	546
862	551	556	561	566	571	576	581	586	591	596
863	601	606	611	616	621	626	631	636	641	646
864	651	656	661	666	671	676	682	687	692	697
865	702	707	712	717	722	727	732	737	742	747
866	752	757	762	767	772	777	782	787	792	797
867	802	807	812	817	822	827	832	837	842	847
868	852	857	862	867	872	877	882	887	892	897
869	902	907	912	917	922	927	932	937	942	947
870	952	957	962	967	972	977	982	987	992	997
871	94 002	007	012	017	022	027	032	037	042	047
872	052	057	062	067	072	077	082	086	091	096
873	101	106	111	116	121	126	131	136	141	146
874	151	156	161	166	171	176	181	186	191	196
875	201	206	211	216	221	226	231	236	240	245
876	250	255	260	265	270	275	280	285	290	295
877	300	305	310	315	320	325	330	335	340	345
878	349	354	359	364	369	374	379	384	389	394
879	399	404	409	414	419	424	429	433	438	443
880	448	453	458	463	468	473	478	483	488	493
881	498	503	507	512	517	522	527	532	537	542
882	547	552	557	562	567	571	576	581	586	591
883	596	601	606	611	616	621	626	630	635	640
884	645	650	655	660	665	670	675	680	685	689
885	694	699	704	709	714	719	724	729	734	738
886	743	748	753	758	763	768	773	778	783	787
887	792	797	802	807	812	817	822	827	832	836
888	841	846	851	856	861	866	871	876	880	885
889	890	895	900	905	910	915	919	924	929	934
890	939	944	949	954	959	963	968	973	978	983
891	988	993	998	*002	*007	*012	*017	*022	*027	*032
892	95 036	041	046	051	056	061	066	071	075	080
893	085	090	095	100	105	109	114	119	124	129
894	134	139	143	148	153	158	163	168	173	177
895	182	187	192	197	202	207	211	216	221	226
896	231	236	240	245	250	255	260	265	270	274
897	279	284	289	294	299	303	308	313	318	323
898	328	332	337	342	347	352	357	361	366	371
899	376	381	386	390	395	400	405	410	415	419
900	424	429	434	439	444	448	453	458	463	468
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

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P. P.

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902	521	525	530	535	540	545	550	554	559	564
903	569	574	578	583	588	593	598	602	607	612
904	617	622	626	631	636	641	646	650	655	660
905	665	670	674	679	684	689	694	698	703	708
906	713	718	722	727	732	737	742	746	751	756
907	761	766	770	775	780	785	789	794	799	804
908	809	813	818	823	828	832	837	842	847	852
909	856	861	866	871	875	880	885	890	895	899
910	904	909	914	918	923	928	933	938	942	947
911	952	957	961	966	971	976	980	985	990	995
912	999	*004	*009	*014	*019	*023	*028	*033	*038	*042
913	96 047	052	057	061	066	071	076	080	085	090
914	095	099	104	109	114	118	123	128	133	137
915	142	147	152	156	161	166	171	175	180	185
916	190	194	199	204	209	213	218	223	227	232
917	237	242	246	251	256	261	265	270	275	280
918	284	289	294	298	303	308	313	317	322	327
919	332	336	341	346	350	355	360	365	369	374
920	379	384	388	393	398	402	407	412	417	421
921	426	431	435	440	445	450	454	459	464	468
922	473	478	483	487	492	497	501	506	511	515
923	520	525	530	534	539	544	548	553	558	562
924	567	572	577	581	586	591	595	600	605	609
925	614	619	624	628	633	638	642	647	652	656
926	661	666	670	675	680	685	689	694	699	703
927	708	713	717	722	727	731	736	741	745	750
928	755	759	764	769	774	778	783	788	792	797
929	802	806	811	816	820	825	830	834	839	844
930	848	853	858	862	867	872	876	881	886	890
931	895	900	904	909	914	918	923	928	932	937
932	942	946	951	956	960	965	970	974	979	984
933	988	993	997	*002	*007	*011	*016	*021	*025	*030
934	97 035	039	044	049	053	058	063	067	072	077
935	081	086	090	095	100	104	109	114	118	123
936	128	132	137	142	146	151	155	160	165	169
937	174	179	183	188	192	197	202	206	211	216
938	220	225	230	234	239	243	248	253	257	262
939	267	271	276	280	285	290	294	299	304	308
940	313	317	322	327	331	336	340	345	350	354
941	359	364	368	373	377	382	387	391	396	400
942	405	410	414	419	424	428	433	437	442	447
943	451	456	460	465	470	474	479	483	488	493
944	497	502	506	511	516	520	525	529	534	539
945	543	548	552	557	562	566	571	575	580	585
946	589	594	598	603	607	612	617	621	626	630
947	635	640	644	649	653	658	663	667	672	676
948	681	685	690	695	699	704	708	713	717	722
949	727	731	736	740	745	749	754	759	763	768
950	772	777	782	786	791	795	800	804	809	813
N.	L. 0	1	2	3	4	5	6	7	8	9

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951	818	823	827	832	836	841	845	850	855	859
952	864	868	873	877	882	886	891	896	900	905
953	909	914	918	923	928	932	937	941	946	950
954	955	959	964	968	973	978	982	987	991	996
955	98 000	005	009	014	019	023	028	032	037	041
956	046	050	055	059	064	068	073	078	082	087
957	091	096	100	105	109	114	118	123	127	132
958	137	141	146	150	155	159	164	168	173	177
959	182	186	191	195	200	204	209	214	218	223
960	227	232	236	241	245	250	254	259	263	268
961	272	277	281	286	290	295	299	304	308	313
962	318	322	327	331	336	340	345	349	354	358
963	363	367	372	376	381	385	390	394	399	403
964	408	412	417	421	426	430	435	439	444	448
965	453	457	462	466	471	475	480	484	489	493
966	498	502	507	511	516	520	525	529	534	538
967	543	547	552	556	561	565	570	574	579	583
968	588	592	597	601	605	610	614	619	623	628
969	632	637	641	646	650	655	659	664	668	673
970	677	682	686	691	695	700	704	709	713	717
971	722	726	731	735	740	744	749	753	758	762
972	767	771	776	780	784	789	793	798	802	807
973	811	816	820	825	829	834	838	843	847	851
974	856	860	865	869	874	878	883	887	892	896
975	900	905	909	914	918	923	927	932	936	941
976	945	949	954	958	963	967	972	976	981	985
977	989	994	998	*003	*007	*012	*016	*021	*025	*029
978	99 034	038	043	047	052	056	061	065	069	074
979	078	083	087	092	096	100	105	109	114	118
980	123	127	131	136	140	145	149	154	158	162
981	167	171	176	180	185	189	193	198	202	207
982	211	216	220	224	229	233	238	242	247	251
983	255	260	264	269	273	277	282	286	291	295
984	300	304	308	313	317	322	326	330	335	339
985	344	348	352	357	361	366	370	374	379	383
986	388	392	396	401	405	410	414	419	423	427
987	432	436	441	445	449	454	458	463	467	471
988	476	480	484	489	493	498	502	506	511	515
989	520	524	528	533	537	542	546	550	555	559
990	564	568	572	577	581	585	590	594	599	603
991	607	612	616	621	625	629	634	638	642	647
992	651	656	660	664	669	673	677	682	686	691
993	695	699	704	708	712	717	721	726	730	734
994	739	743	747	752	756	760	765	769	774	778
995	782	787	791	795	800	804	808	813	817	822
996	826	830	835	839	843	848	852	856	861	865
997	870	874	878	883	887	891	896	900	904	909
998	913	917	922	926	930	935	939	944	948	952
999	957	961	965	970	974	978	983	987	991	996
1000	00 000	004	009	013	017	022	026	030	035	039
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

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P. P.

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″	′	L. Sin.	d.	Cpl. S.	Cpl. T.	L. Tang.	d. c.	L. Cotg.	L. Cos.	
°	0	—		—	—	—		—	0.00000	60
60	1	6.46373	30103	5.31443	5.31443	6.46373	30103	3.53627	0.00000	59
120	2	6.76476	17609	5.31443	5.31443	6.76476	17609	3.23524	0.00000	58
180	3	6.94085	12494	5.31443	5.31443	6.94085	12494	3.05915	0.00000	57
240	4	7.06579	9691	5.31443	5.31442	7.06579	9691	2.93421	0.00000	56
300	5	7.16270	7918	5.31443	5.31442	7.16270	7918	2.83730	0.00000	55
360	6	7.24188	6694	5.31443	5.31442	7.24188	6694	2.75812	0.00000	54
420	7	7.30882	5800	5.31443	5.31442	7.30882	5800	2.69118	0.00000	53
480	8	7.36682	5115	5.31443	5.31442	7.36682	5115	2.63318	0.00000	52
540	9	7.41797	4576	5.31443	5.31442	7.41797	4576	2.58203	0.00000	51
600	10	7.46373	4139	5.31443	5.31442	7.46373	4139	2.53627	0.00000	50
660	11	7.50512	3779	5.31443	5.31442	7.50512	3779	2.49488	0.00000	49
720	12	7.54291	3476	5.31443	5.31442	7.54291	3476	2.45709	0.00000	48
780	13	7.57767	3218	5.31443	5.31442	7.57767	3219	2.42233	0.00000	47
840	14	7.60985	2997	5.31443	5.31442	7.60986	2996	2.39014	0.00000	46
900	15	7.63982	2802	5.31443	5.31442	7.63982	2803	2.36018	0.00000	45
960	16	7.66784	2633	5.31443	5.31442	7.66785	2633	2.33215	0.00000	44
1020	17	7.69417	2483	5.31443	5.31442	7.69418	2482	2.30582	9.99999	43
1080	18	7.71900	2348	5.31443	5.31442	7.71900	2348	2.28100	9.99999	42
1140	19	7.74248	2227	5.31443	5.31442	7.74248	2228	2.25752	9.99999	41
1200	20	7.76475	2119	5.31443	5.31442	7.76476	2119	2.23524	9.99999	40
1260	21	7.78594	2021	5.31443	5.31442	7.78595	2020	2.21405	9.99999	39
1320	22	7.80615	1930	5.31443	5.31442	7.80615	1931	2.19385	9.99999	38
1380	23	7.82545	1848	5.31443	5.31442	7.82546	1848	2.17454	9.99999	37
1440	24	7.84393	1773	5.31443	5.31442	7.84394	1773	2.15606	9.99999	36
1500	25	7.86166	1704	5.31443	5.31442	7.86167	1704	2.13833	9.99999	35
1560	26	7.87870	1639	5.31443	5.31442	7.87871	1639	2.12129	9.99999	34
1620	27	7.89509	1579	5.31443	5.31442	7.89510	1579	2.10490	9.99999	33
1680	28	7.91088	1524	5.31443	5.31442	7.91089	1524	2.08911	9.99999	32
1740	29	7.92612	1472	5.31443	5.31441	7.92613	1473	2.07387	9.99998	31
1800	30	7.94084	1424	5.31443	5.31441	7.94086	1424	2.05914	9.99998	30
1860	31	7.95508	1379	5.31443	5.31441	7.95510	1379	2.04490	9.99998	29
1920	32	7.96887	1336	5.31443	5.31441	7.96889	1336	2.03111	9.99998	28
1980	33	7.98223	1297	5.31443	5.31441	7.98225	1297	2.01775	9.99998	27
2040	34	7.99520	1259	5.31443	5.31441	7.99522	1259	2.00478	9.99998	26
2100	35	8.00779	1223	5.31443	5.31441	8.00781	1223	1.99219	9.99998	25
2160	36	8.02002	1190	5.31443	5.31441	8.02004	1190	1.97996	9.99998	24
2220	37	8.03192	1158	5.31443	5.31441	8.03194	1159	1.96806	9.99997	23
2280	38	8.04350	1128	5.31443	5.31441	8.04353	1128	1.95647	9.99997	22
2340	39	8.05478	1100	5.31443	5.31441	8.05481	1100	1.94519	9.99997	21
2400	40	8.06578	1072	5.31443	5.31441	8.06581	1072	1.93419	9.99997	20
2460	41	8.07650	1046	5.31444	5.31440	8.07653	1047	1.92347	9.99997	19
2520	42	8.08696	1022	5.31444	5.31440	8.08700	1022	1.91300	9.99997	18
2580	43	8.09718	999	5.31444	5.31440	8.09722	998	1.90278	9.99997	17
2640	44	8.10717	976	5.31444	5.31440	8.10720	976	1.89280	9.99996	16
2700	45	8.11693	954	5.31444	5.31440	8.11696	955	1.88304	9.99996	15
2760	46	8.12647	934	5.31444	5.31440	8.12651	934	1.87349	9.99996	14
2820	47	8.13581	914	5.31444	5.31440	8.13585	915	1.86415	9.99996	13
2880	48	8.14495	896	5.31444	5.31440	8.14500	895	1.85500	9.99996	12
2940	49	8.15391	877	5.31444	5.31440	8.15395	878	1.84605	9.99996	11
3000	50	8.16268	860	5.31444	5.31439	8.16273	860	1.83727	9.99995	10
3060	51	8.17128	843	5.31444	5.31439	8.17133	843	1.82867	9.99995	9
3120	52	8.17971	827	5.31444	5.31439	8.17976	828	1.82024	9.99995	8
3180	53	8.18798	812	5.31444	5.31439	8.18804	812	1.81196	9.99995	7
3240	54	8.19610	797	5.31444	5.31439	8.19616	797	1.80384	9.99995	6
3300	55	8.20407	782	5.31444	5.31439	8.20413	782	1.79587	9.99994	5
3360	56	8.21189	769	5.31444	5.31439	8.21195	769	1.78805	9.99994	4
3420	57	8.21958	755	5.31445	5.31439	8.21964	756	1.78036	9.99994	3
3480	58	8.22713	743	5.31445	5.31438	8.22720	742	1.77280	9.99994	2
3540	59	8.23456	730	5.31445	5.31438	8.23462	730	1.76538	9.99994	1
3600	60	8.24186		5.31445	5.31438	8.24192		1.75808	9.99993	0
		L. Cos.	d.			L. Cotg.	d. c.	L. Tang.	L. Sin.	′

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3600	0	8.24186	717	5.31445	5.31438	8.24192	718	1.75808	9.99993	60
3660	1	8.24903	706	5.31445	5.31438	8.24910	706	1.75090	9.99993	59
3720	2	8.25609	695	5.31445	5.31438	8.25616	696	1.74384	9.99993	58
3780	3	8.26304	684	5.31445	5.31438	8.26312	684	1.73688	9.99993	57
3840	4	8.26988	673	5.31445	5.31437	8.26996	673	1.73004	9.99992	56
3900	5	8.27661	663	5.31445	5.31437	8.27669	663	1.72331	9.99992	55
3960	6	8.28324	653	5.31445	5.31437	8.28332	654	1.71668	9.99992	54
4020	7	8.28977	644	5.31445	5.31437	8.28986	643	1.71014	9.99992	53
4080	8	8.29621	634	5.31445	5.31437	8.29629	634	1.70371	9.99992	52
4140	9	8.30255	624	5.31445	5.31437	8.30263	625	1.69737	9.99991	51
4200	10	8.30879	616	5.31446	5.31437	8.30888	617	1.69112	9.99991	50
4260	11	8.31495	608	5.31446	5.31436	8.31505	607	1.68495	9.99991	49
4320	12	8.32103	599	5.31446	5.31436	8.32112	599	1.67888	9.99990	48
4380	13	8.32702	590	5.31446	5.31436	8.32711	591	1.67289	9.99990	47
4440	14	8.33292	583	5.31446	5.31436	8.33302	584	1.66698	9.99990	46
4500	15	8.33875	575	5.31446	5.31436	8.33886	575	1.66114	9.99990	45
4560	16	8.34450	568	5.31446	5.31435	8.34461	568	1.65539	9.99989	44
4620	17	8.35018	560	5 31446	5.31435	8.35029	561	1.64971	9.99989	43
4680	18	8.35578	553	5.31446	5.31435	8.35590	553	1.64410	9.99989	42
4740	19	8.36131	547	5.31446	5.31435	8.36143	546	1.63857	9.99989	41
4800	20	8.36678	539	5.31446	5.31435	8.36689	540	1.63311	9.99988	40
4860	21	8.37217	533	5.31447	5.31434	8.37229	533	1.62771	9.99988	39
4920	22	8.37750	526	5.31447	5.31434	8.37762	527	1.62238	9.99988	38
4980	23	8.38276	520	5.31447	5.31434	8.38289	520	1.61711	9.99987	37
5040	24	8.38796	514	5.31447	5.31434	8.38809	514	1.61191	9.99987	36
5100	25	8.39310	508	5.31447	5.31434	8.39323	509	1.60677	9.99987	35
5160	26	8.39818	502	5.31447	5.31433	8.39832	502	1.60168	9.99986	34
5220	27	8.40320	496	5.31447	5.31433	8.40334	496	1.59666	9.99986	33
5280	28	8.40816	491	5.31447	5.31433	8.40830	491	1.59170	9.99986	32
5340	29	8.41307	485	5.31447	5.31433	8.41321	486	1.58679	9.99985	31
5400	30	8.41792	480	5.31447	5.31433	8.41807	480	1.58193	9.99985	30
5460	31	8.42272	474	5.31448	5.31432	8.42287	475	1.57713	9.99985	29
5520	32	8.42746	470	5.31448	5.31432	8.42762	470	1.57238	9.99984	28
5580	33	8.43216	464	5.31448	5.31432	8.43232	464	1.56768	9.99984	27
5640	34	8.43680	459	5.31448	5.31432	8.43696	460	1.56304	9.99984	26
5700	35	8.44139	455	5.31448	5.31431	8.44156	455	1.55844	9.99983	25
5760	36	8.44594	450	5.31448	5.31431	8.44611	450	1.55389	9.99983	24
5820	37	8.45044	445	5.31448	5.31431	8.45061	446	1.54939	9.99983	23
5880	38	8.45489	441	5.31448	5.31431	8.45507	441	1.54493	9.99982	22
5940	39	8.45930	436	5.31449	5.31431	8.45948	437	1.54052	9.99982	21
6000	40	8.46366	433	5.31449	5.31430	8.46385	432	1.53615	9.99982	20
6060	41	8.46799	427	5.31449	5.31430	8.46817	428	1.53183	9.99981	19
6120	42	8.47226	424	5.31449	5.31430	8.47245	424	1.52755	9.99981	18
6180	43	8.47650	419	5.31449	5.31430	8.47669	420	1.52331	9.99981	17
6240	44	8.48069	416	5.31449	5.31429	8.48089	416	1.51911	9.99980	16
6300	45	8.48485	411	5.31449	5.31429	8.48505	412	1.51495	9.99980	15
6360	46	8.48896	408	5.31449	5.31429	8.48917	408	1.51083	9.99979	14
6420	47	8.49304	404	5.31450	5.31428	8.49325	404	1.50675	9.99979	13
6480	48	8.49708	400	5.31450	5.31428	8.49729	401	1.50271	9.99979	12
6540	49	8.50108	396	5.31450	5.31428	8.50130	397	1.49870	9.99978	11
6600	50	8.50504	393	5.31450	5.31428	8.50527	393	1.49473	9.99978	10
6660	51	8.50897	390	5.31450	5.31427	8.50920	390	1.49080	9.99977	9
6720	52	8.51287	386	5.31450	5.31427	8.51310	386	1.48690	9.99977	8
6780	53	8.51673	382	5.31450	5.31427	8.51696	383	1.48304	9.99977	7
6840	54	8.52055	379	5.31450	5.31427	8.52079	380	1.47921	9.99976	6
6900	55	8.52434	376	5.31451	5.31426	8.52459	376	1.47541	9.99976	5
6960	56	8.52810	373	5.31451	5.31426	8.52835	373	1.47165	9.99975	4
7020	57	8.53183	369	5.31451	5.31426	8.53208	370	1.46792	9.99975	3
7080	58	8.53552	367	5.31451	5.31425	8.53578	367	1.46422	9.99974	2
7140	59	8.53919	363	5.31451	5.31425	8.53945	363	1.46055	9.99974	1
7200	60	8.54282		5.31451	5.31425	8.54308		1.45692	9.99974	0
		L. Cos.	d.			L. Cotg.	d. c.	L. Tang.	L. Sin.	′

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2°

″	′	L. Sin.	d.	Cpl. S.	Cpl. T.	L. Tang.	d. c.	L. Cotg.	L. Cos.	
7200	0	8.54282	360	5.31451	5.31425	8.54308	361	1.45692	9.99974	60
7260	1	8.54642	357	5.31451	5.31425	8.54669	358	1.45331	9.99973	59
7320	2	8.54999	355	5.31452	5.31424	8.55027	355	1.44973	9.99973	58
7380	3	8.55354	351	5.31452	5.31424	8.55382	352	1.44618	9.99972	57
7440	4	8.55705	349	5.31452	5.31424	8.55734	349	1.44266	9.99972	56
7500	5	8.56054	346	5.31452	5.31423	8.56083	346	1.43917	9.99971	55
7560	6	8.56400	343	5.31452	5.31423	8.56429	344	1.43571	9.99971	54
7620	7	8.56743	341	5.31452	5.31423	8.56773	341	1.43227	9.99970	53
7680	8	8.57084	337	5.31453	5.31422	8.57114	338	1.42886	9.99970	52
7740	9	8.57421	336	5.31453	5.31422	8.57452	336	1.42548	9.99969	51
7800	10	8.57757	332	5.31453	5.31422	8.57788	333	1.42212	9.99969	50
7860	11	8.58089	330	5.31453	5.31421	8.58121	330	1.41879	9.99968	49
7920	12	8.58419	328	5.31453	5.31421	8.58451	328	1.41549	9.99968	48
7980	13	8.58747	325	5.31453	5.31421	8.58779	326	1.41221	9.99967	47
8040	14	8.59072	323	5.31454	5.31421	8.59105	323	1.40895	9.99967	46
8100	15	8.59395	320	5.31454	5.31420	8.59428	321	1.40572	9.99967	45
8160	16	8.59715	318	5.31454	5.31420	8.59749	319	1.40251	9.99966	44
8220	17	8.60033	316	5.31454	5.31420	8.60068	316	1.39932	9.99966	43
8280	18	8.60349	313	5.31454	5.31419	8.60384	314	1.39616	9.99965	42
8340	19	8.60662	311	5.31454	5.31419	8.60698	311	1.39302	9.99964	41
8400	20	8.60973	309	5.31455	5.31418	8.61009	310	1.38991	9.99964	40
8460	21	8.61282	307	5.31455	5.31418	8.61319	307	1.38681	9.99963	39
8520	22	8.61589	305	5.31455	5.31418	8.61626	305	1.38374	9.99963	38
8580	23	8.61894	302	5.31455	5.31417	8.61931	303	1.38069	9.99962	37
8640	24	8.62196	301	5.31455	5.31417	8.62234	301	1.37766	9.99962	36
8700	25	8.62497	298	5.31455	5.31417	8.62535	299	1.37465	9.99961	35
8760	26	8.62795	296	5.31456	5.31416	8.62834	297	1.37166	9.99961	34
8820	27	8.63091	294	5.31456	5.31416	8.63131	295	1.36869	9.99960	33
8880	28	8.63385	293	5.31456	5.31416	8.63426	292	1.36574	9.99960	32
8940	29	8.63678	290	5.31456	5.31415	8.63718	291	1.36282	9.99959	31
9000	30	8.63968	288	5.31456	5.31415	8.64009	289	1.35991	9.99959	30
9060	31	8.64256	287	5.31456	5.31415	8.64298	287	1.35702	9.99958	29
9120	32	8.64543	284	5.31457	5.31414	8.64585	285	1.35415	9.99958	28
9180	33	8.64827	283	5.31457	5.31414	8.64870	284	1.35130	9.99957	27
9240	34	8.65110	281	5.31457	5.31413	8.65154	281	1.34846	9.99956	26
9300	35	8.65391	279	5.31457	5.31413	8.65435	280	1.34565	9.99956	25
9360	36	8.65670	277	5.31457	5.31413	8.65715	278	1.34285	9.99955	24
9420	37	8.65947	276	5.31458	5.31412	8.65993	276	1.34007	9.99955	23
9480	38	8.66223	274	5.31458	5.31412	8.66269	274	1.33731	9.99954	22
9540	39	8.66497	272	5.31458	5.31412	8.66543	273	1.33457	9.99954	21
9600	40	8.66769	270	5.31458	5.31411	8.66816	271	1.33184	9.99953	20
9660	41	8.67039	269	5.31458	5.31411	8.67087	269	1.32913	9.99952	19
9720	42	8.67308	267	5.31459	5.31410	8.67356	268	1.32644	9.99952	18
9780	43	8.67575	266	5.31459	5.31410	8.67624	266	1.32376	9.99951	17
9840	44	8.67841	263	5.31459	5.31410	8.67890	264	1.32110	9.99951	16
9900	45	8.68104	263	5.31459	5.31409	8.68154	263	1.31846	9.99950	15
9960	46	8.68367	260	5.31459	5.31409	8.68417	261	1.31583	9.99949	14
10020	47	8.68627	259	5.31460	5.31408	8.68678	260	1.31322	9.99949	13
10080	48	8.68886	258	5.31460	5.31408	8.68938	258	1.31062	9.99948	12
10140	49	8.69144	256	5.31460	5.31408	8.69196	257	1.30804	9.99948	11
10200	50	8.69400	254	5.31460	5.31407	8.69453	255	1.30547	9.99947	10
10260	51	8.69654	253	5.31460	5.31407	8.69708	254	1.30292	9.99946	9
10320	52	8.69907	252	5.31461	5.31406	8.69962	252	1.30038	9.99946	8
10380	53	8.70159	250	5.31461	5.31406	8.70214	251	1.29786	9.99945	7
10440	54	8.70409	249	5.31461	5.31405	8.70465	249	1.29535	9.99944	6
10500	55	8.70658	247	5.31461	5.31405	8.70714	248	1.29286	9.99944	5
10560	56	8.70905	246	5.31461	5.31405	8.70962	246	1.29038	9.99943	4
10620	57	8.71151	244	5.31462	5.31404	8.71208	245	1.28792	9.99942	3
10680	58	8.71395	243	5.31462	5.31404	8.71453	244	1.28547	9.99942	2
10740	59	8.71638	242	5.31462	5.31403	8.71697	243	1.28303	9.99941	1
10800	60	8.71880		5.31462	5.31403	8.71940		1.28060	9.99940	0
		L. Cos.	d.			L. Cotg.	d. c.	L. Tang.	L. Sin.	′

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3°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	
0	8.71880	240	8.71940	241	1.28060	9.99940	60
1	8.72120	239	8.72181	239	1.27819	9.99940	59
2	8.72359	238	8.72420	239	1.27580	9.99939	58
3	8.72597	237	8.72659	237	1.27341	9.99938	57
4	8.72834	235	8.72896	236	1.27104	9.99938	56
5	8.73069	234	8.73132	234	1.26868	9.99937	55
6	8.73303	232	8.73366	234	1.26634	9.99936	54
7	8.73535	232	8.73600	232	1.26400	9.99936	53
8	8.73767	230	8.73832	231	1.26168	9.99935	52
9	8.73997	229	8.74063	229	1.25937	9.99934	51
10	8.74226	228	8.74292	229	1.25708	9.99934	50
11	8.74454	226	8.74521	227	1.25479	9.99933	49
12	8.74680	226	8.74748	226	1.25252	9.99932	48
13	8.74906	224	8.74974	225	1.25026	9.99932	47
14	8.75130	223	8.75199	224	1.24801	9.99931	46
15	8.75353	222	8.75423	222	1.24577	9.99930	45
16	8.75575	220	8.75645	222	1.24355	9.99929	44
17	8.75795	220	8.75867	220	1.24133	9.99929	43
18	8.76015	219	8.76087	219	1.23913	9.99928	42
19	8.76234	217	8.76306	219	1.23694	9.99927	41
20	8.76451	216	8.76525	217	1.23475	9.99926	40
21	8.76667	216	8.76742	216	1.23258	9.99926	39
22	8.76883	214	8.76958	215	1.23042	9.99925	38
23	8.77097	213	8.77173	214	1.22827	9.99924	37
24	8.77310	212	8.77387	213	1.22613	9.99923	36
25	8.77522	211	8.77600	211	1.22400	9.99923	35
26	8.77733	210	8.77811	211	1.22189	9.99922	34
27	8.77943	209	8.78022	210	1.21978	9.99921	33
28	8.78152	208	8.78232	209	1.21768	9.99920	32
29	8.78360	208	8.78441	208	1.21559	9.99920	31
30	8.78568	206	8.78649	206	1.21351	9.99919	30
31	8.78774	205	8.78855	206	1.21145	9.99918	29
32	8.78979	204	8.79061	205	1.20939	9.99917	28
33	8.79183	203	8.79266	204	1.20734	9.99917	27
34	8.79386	202	8.79470	203	1.20530	9.99916	26
35	8.79588	201	8.79673	202	1.20327	9.99915	25
36	8.79789	201	8.79875	201	1.20125	9.99914	24
37	8.79990	199	8.80076	201	1.19924	9.99913	23
38	8.80189	199	8.80277	199	1.19723	9.99913	22
39	8.80388	197	8.80476	198	1.19524	9.99912	21
40	8.80585	197	8.80674	198	1.19326	9.99911	20
41	8.80782	196	8.80872	196	1.19128	9.99910	19
42	8.80978	195	8.81068	196	1.18932	9.99909	18
43	8.81173	194	8.81264	195	1.18736	9.99909	17
44	8.81367	193	8.81459	194	1.18541	9.99908	16
45	8.81560	192	8.81653	193	1.18347	9.99907	15
46	8.81752	192	8.81846	192	1.18154	9.99906	14
47	8.81944	190	8.82038	192	1.17962	9.99905	13
48	8.82134	190	8.82230	190	1.17770	9.99904	12
49	8.82324	189	8.82420	190	1.17580	9.99904	11
50	8.82513	188	8.82610	189	1.17390	9.99903	10
51	8.82701	187	8.82799	188	1.17201	9.99902	9
52	8.82888	187	8.82987	188	1.17013	9.99901	8
53	8.83075	186	8.83175	186	1.16825	9.99900	7
54	8.83261	185	8.83361	186	1.16639	9.99899	6
55	8.83446	184	8.83547	185	1.16453	9.99898	5
56	8.83630	183	8.83732	184	1.16268	9.99898	4
57	8.83813	183	8.83916	184	1.16084	9.99897	3
58	8.83996	181	8.84100	182	1.15900	9.99896	2
59	8.84177	181	8.84282	182	1.15718	9.99895	1
60	8.84358		8.84464		1.15536	9.99894	0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	′

P. P.

	238	234	229
6	23.8	23.4	22.9
7	27.8	27.3	26.7
8	31.7	31.2	30.5
9	35.7	35.1	34.4
10	39.7	39.0	38.2
20	79.3	78.0	76.3
30	119.0	117.0	114.5
40	158.7	156.0	152.7
50	198.3	195.0	190.8

	225	220	216
6	22.5	22.0	21.6
7	26.3	25.7	25.2
8	30.0	29.3	28.8
9	33.8	33.0	32.4
10	37.5	36.7	36.0
20	75.0	73.3	72.0
30	112.5	110.0	108.0
40	150.0	146.7	144.0
50	187.5	183.3	180.0

	212	208	204
6	21.2	20.8	20.4
7	24.7	24.3	23.8
8	28.3	27.7	27.2
9	31.8	31.2	30.6
10	35.3	34.7	34.0
20	70.7	69.3	68.0
30	106.0	104.0	102.0
40	141.3	138.7	136.0
50	176.7	173.3	170.0

	201	197	193
6	20.1	19.7	19.3
7	23.5	23.0	22.5
8	26.8	26.3	25.7
9	30.2	29.6	29.0
10	33.5	32.8	32.2
20	67.0	65.7	64.3
30	100.5	98.5	96.5
40	134.0	131.3	128.7
50	167.5	164.2	160.8

	189	185	181
6	18.9	18.5	18.1
7	22.1	21.6	21.1
8	25.2	24.7	24.1
9	28.4	27.8	27.2
10	31.5	30.8	30.2
20	63.0	61.7	60.3
30	94.5	92.5	90.5
40	126.0	123.3	120.7
50	157.5	154.2	150.8

	4	3	2	1
6	0.4	0.3	0.2	0.1
7	0.5	0.4	0.2	0.1
8	0.5	0.4	0.3	0.1
9	0.6	0.5	0.3	0.2
10	0.7	0.5	0.3	0.2
20	1.3	1.0	0.7	0.3
30	2.0	1.5	1.0	0.5
40	2.7	2.0	1.3	0.7
50	3.3	2.5	1.7	0.8

P. P.

86°

4°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	
0	8.84358	181	8.84464	182	1.15536	9.99894	60
1	8.84539	179	8.84646	180	1.15354	9.99893	59
2	8.84718	179	8.84826	180	1.15174	9.99892	58
3	8.84897	178	8.85006	179	1.14994	9.99891	57
4	8.85075	177	8.85185	178	1.14815	9.99891	56
5	8.85252	177	8.85363	177	1.14637	9.99890	55
6	8.85429	176	8.85540	177	1.14460	9.99889	54
7	8.85605	175	8.85717	176	1.14283	9.99888	53
8	8.85780	175	8.85893	176	1.14107	9.99887	52
9	8.85955	173	8.86069	174	1.13931	9.99886	51
10	8.86128	173	8.86243	174	1.13757	9.99885	50
11	8.86301	173	8.86417	174	1.13583	9.99884	49
12	8.86474	171	8.86591	172	1.13409	9.99883	48
13	8.86645	171	8.86763	172	1.13237	9.99882	47
14	8.86816	171	8.86935	171	1.13065	9.99881	46
15	8.86987	169	8.87106	171	1.12894	9.99880	45
16	8.87156	169	8.87277	170	1.12723	9.99879	44
17	8.87325	169	8.87447	169	1.12553	9 99879	43
18	8.87494	167	8.87616	169	1.12384	9.99878	42
19	8.87661	168	8.87785	168	1.12215	9.99877	41
20	8.87829	166	8.87953	167	1.12047	9.99876	40
21	8.87995	166	8.88120	167	1.11880	9.99875	39
22	8.88161	165	8.88287	166	1.11713	9.99874	38
23	8.88326	164	8.88453	165	1.11547	9.99873	37
24	8.88490	164	8.88618	165	1.11382	9.99872	36
25	8.88654	163	8.88783	165	1.11217	9.99871	35
26	8.88817	163	8.88948	163	1.11052	9.99870	34
27	8.88980	162	8.89111	163	1.10889	9.99869	33
28	8.89142	162	8.89274	163	1.10726	9.99868	32
29	8.89304	160	8.89437	161	1.10563	9.99867	31
30	8.89464	161	8.89598	162	1.10402	9.99866	30
31	8.89625	159	8.89760	160	1.10240	9.99865	29
32	8.89784	159	8.89920	160	1.10080	9.99864	28
33	8.89943	159	8.90080	160	1.09920	9.99863	27
34	8.90102	158	8.90240	159	1.09760	9.99862	26
35	8.90260	157	8.90399	158	1.09601	9.99861	25
36	8.90417	157	8.90557	158	1.09443	9.99860	24
37	8.90574	156	8.90715	157	1.09285	9.99859	23
38	8.90730	155	8.90872	157	1.09128	9.99858	22
39	8.90885	155	8.91029	156	1.08971	9.99857	21
40	8.91040	155	8.91185	155	1.08815	9.99856	20
41	8.91195	154	8.91340	155	1.08660	9.99855	19
42	8.91349	153	8.91495	155	1.08505	9.99854	18
43	8.91502	153	8.91650	153	1.08350	9.99853	17
44	8.91655	152	8.91803	154	1.08197	9.99852	16
45	8.91807	152	8.91957	153	1.08043	9.99851	15
46	8.91959	151	8.92110	152	1.07890	9.99850	14
47	8.92110	151	8.92262	152	1.07738	9.99848	13
48	8.92261	150	8.92414	151	1.07586	9.99847	12
49	8.92411	150	8.92565	151	1.07435	9.99846	11
50	8.92561	149	8.92716	150	1.07284	9.99845	10
51	8.92710	149	8.92866	150	1.07134	9.99844	9
52	8.92859	148	8.93016	149	1.06984	9.99843	8
53	8.93007	147	8.93165	148	1.06835	9.99842	7
54	8.93154	147	8.93313	149	1.06687	9.99841	6
55	8.93301	147	8.93462	147	1.06538	9.99840	5
56	8.93448	146	3.93609	147	1.06391	9.99839	4
57	8.93594	146	8.93756	147	1.06244	9.99838	3
58	8.93740	145	8.93903	146	1.06097	9.99837	2
59	8.93885	145	8.94049	146	1.05951	9.99836	1
60	8.94030		8.94195		1.05805	9.99834	0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	′

P. P.

	181	179	177
6	18.1	17.9	17.7
7	21.1	20.9	20.7
8	24.1	23.9	23.6
9	27.2	26.9	26.6
10	30.2	29.8	29.5
20	60.3	59.7	59.0
30	90.5	89.5	88.5
40	120.7	119.3	118.0
50	150.8	149.2	147.5

	175	173	171
6	17.5	17.3	17.1
7	20.4	20.2	20.0
8	23.3	23.1	22.8
9	26.3	26.0	25.7
10	29.2	28.8	28.5
20	58.3	57.7	57.0
30	87.5	86.5	85.5
40	116.7	115.3	114.0
50	145.8	144.2	142.5

	168	166	164
6	16.8	16.6	16.4
7	19.6	19.4	19.1
8	22.4	22.1	21.9
9	25.2	24.9	24.6
10	28.0	27.7	27.3
20	56.0	55.3	54.7
30	84.0	83.0	82.0
40	112.0	110.7	109.3
50	140.0	138.3	136.7

	162	159	157
6	16.2	15.9	15.7
7	18.9	18.6	18.3
8	21.6	21.2	20.9
9	24.3	23.9	23.6
10	27.0	26.5	26.2
20	54.0	53.0	52.3
30	81.0	79.5	78.5
40	108.0	106.0	104.7
50	135.0	132.5	130.8

	155	153	151
6	15.5	15.3	15.1
7	18.1	17.9	17.6
8	20.7	20.4	20.1
9	23.3	23.0	22.7
10	25.8	25.5	25.2
20	51.7	51.0	50.3
30	77.5	76.5	75.5
40	103.3	102.0	100.7
50	129.2	127.5	125.8

	149	147	1
6	14.9	14.7	0.1
7	17.4	17.2	0.1
8	19.9	19.6	0.1
9	22.4	22.1	0.2
10	24.8	24.5	0.2
20	49.7	49.0	0.3
30	74.5	73.5	0.5
40	99.3	98.0	0.7
50	124.2	122.5	0.8

P. P.

85°

5°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	
0	8.94030	144	8.94195	145	1.05805	9.99834	60
1	8.94174	143	8.94340	145	1.05660	9.99833	59
2	8.94317	144	8.94485	145	1.05515	9.99832	58
3	8.94461	142	8.94630	143	1.05370	9.99831	57
4	8.94603	143	8.94773	144	1.05227	9.99830	56
5	8.94746	141	8.94917	143	1.05083	9.99829	55
6	8.94887	142	8.95060	142	1.04940	9.99828	54
7	8.95029	141	8.95202	142	1.04798	9.99827	53
8	8.95170	140	8.95344	142	1.04656	9.99825	52
9	8.95310	140	8.95486	141	1.04514	9.99824	51
10	8.95450	139	8.95627	140	1.04373	9.99823	50
11	8.95589	139	8.95767	141	1.04233	9.99822	49
12	8.95728	139	8.95908	139	1.04092	9.99821	48
13	8.95867	138	8.96047	140	1.03953	9.99820	47
14	8.96005	138	8.96187	138	1.03813	9.99819	46
15	8.96143	137	8.96325	139	1.03675	9.99817	45
16	8.96280	137	8.96464	138	1.03536	9.99816	44
17	8.96417	136	8.96602	137	1.03398	9.99815	43
18	8.96553	136	8.96739	138	1.03261	9.99814	42
19	8.96689	136	8.96877	136	1.03123	9.99813	41
20	8.96825	135	8.97013	137	1.02987	9.99812	40
21	8.96960	135	8.97150	135	1.02850	9.99810	39
22	8.97095	134	8.97285	136	1.02715	9.99809	38
23	8.97229	134	8.97421	135	1.02579	9.99808	37
24	8.97363	133	8.97556	135	1.02444	9.99807	36
25	8.97496	133	8.97691	134	1.02309	9.99806	35
26	8.97629	133	8.97825	134	1.02175	9.99804	34
27	8.97762	132	8.97959	133	1.02041	9.99803	33
28	8.97894	132	8.98092	133	1.01908	9.99802	32
29	8.98026	131	8.98225	133	1.01775	9.99801	31
30	8.98157	131	8.98358	132	1.01642	9.99800	30
31	8.98288	131	8.98490	132	1.01510	9.99798	29
32	8.98419	130	8.98622	131	1.01378	9.99797	28
33	8.98549	130	8.98753	131	1.01247	9.99796	27
34	8.98679	129	8.98884	131	1.01116	9.99795	26
35	8.98808	129	8.99015	130	1.00985	9.99793	25
36	8.98937	129	8.99145	130	1.00855	9.99792	24
37	8.99066	128	8.99275	130	1.00725	9.99791	23
38	8.99194	128	8.99405	129	1.00595	9.99790	22
39	8.99322	128	8.99534	128	1.00466	9.99788	21
40	8.99450	127	8.99662	129	1.00338	9.99787	20
41	8.99577	127	8.99791	128	1.00209	9.99786	19
42	8.99704	126	8.99919	127	1.00081	9.99785	18
43	8.99830	126	9.00046	128	0.99954	9.99783	17
44	8.99956	126	9.00174	127	0.99826	9.99782	16
45	9.00082	125	9.00301	126	0.99699	9.99781	15
46	9.00207	125	9.00427	126	0.99573	9.99780	14
47	9.00332	124	9.00553	126	0.99447	9.99778	13
48	9.00456	125	9.00679	126	0.99321	9.99777	12
49	9.00581	123	9.00805	125	0.99195	9.99776	11
50	9.00704	124	9.00930	125	0.99070	9.99775	10
51	9.00828	123	9.01055	124	0.98945	9.99773	9
52	9.00951	123	9.01179	124	0.98821	9.99772	8
53	9.01074	122	9.01303	124	0.98697	9.99771	7
54	9.01196	122	9.01427	123	0.98573	9.99769	6
55	9.01318	122	9.01550	123	0.98450	9.99768	5
56	9.01440	121	9.01673	123	0.98327	9.99767	4
57	9.01561	121	9.01796	122	0.98204	9.99765	3
58	9.01682	121	9.01918	122	0.98082	9.99764	2
59	9.01803	120	9.02040	122	0.97960	9.99763	1
60	9.01923		9.02162		0.97838	9.99761	0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	′

P. P.

	145	143	141
6	14.5	14.3	14.1
7	16.9	16.7	16.5
8	19.3	19.1	18.8
9	21.8	21.5	21.2
10	24.2	23.8	23.5
20	48.3	47.7	47.0
30	72.5	71.5	70.5
40	96.7	95.3	94.0
50	120.8	119.2	117.5

	139	138	136
6	13.9	13.8	13.6
7	16.2	16.1	15.9
8	18.5	18.4	18.1
9	20.9	20.7	20.4
10	23.2	23.0	22.7
20	46.3	46.0	45.3
30	69.5	69.0	68.0
40	92.7	92.0	90.7
50	115.8	115.0	113.3

	135	133	131
6	13.5	13.3	13.1
7	15.8	15.5	15.3
8	18.0	17.7	17.5
9	20.3	20.0	19.7
10	22.5	22.2	21.8
20	45.0	44.3	43.7
30	67.5	66.5	65.5
40	90.0	88.7	87.3
50	112.5	110.8	109.2

	129	128	126
6	12.9	12.8	12.6
7	15.1	14.9	14.7
8	17.2	17.1	16.8
9	19.4	19.2	18.9
10	21.5	21.3	21.0
20	43.0	42.7	42.0
30	64.5	64.0	63.0
40	86.0	85.3	84.0
50	107.5	106.7	105.0

	125	123	122
6	12.5	12.3	12.2
7	14.6	14.4	14.2
8	16.7	16.4	16.3
9	18.8	18.5	18.3
10	20.8	20.5	20.3
20	41.7	41.0	40.7
30	62.5	61.5	61.0
40	83.3	82.0	81.3
50	104.2	102.5	101.7

	121	120	1
6	12.1	12.0	0.1
7	14.1	14.0	0.1
8	16.1	16.0	0.1
9	18.2	18.0	0.2
10	20.2	20.0	0.2
20	40.3	40.0	0.3
30	60.5	60.0	0.5
40	80.7	80.0	0.7
50	100.8	100.0	0.8

P. P.

84°

6°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	
0	9.01923	120	9.02162	121	0.97838	9.99761	60
1	9.02043	120	9.02283	121	0.97717	9.99760	59
2	9.02163	120	9.02404	121	0.97596	9.99759	58
3	9.02283	119	9.02525	120	0.97475	9.99757	57
4	9.02402	118	9.02645	121	0.97355	9.99756	56
5	9.02520	119	9.02766	119	0.97234	9.99755	55
6	9.02639	118	9.02885	120	0.97115	9.99753	54
7	9.02757	117	9.03005	119	0.96995	9.99752	53
8	9.02874	118	9.03124	118	0.96876	9.99751	52
9	9.02992	117	9.03242	119	0.96758	9.99749	51
10	9.03109	117	9.03361	118	0.96639	9.99748	50
11	9.03226	116	9.03479	118	0.96521	9.99747	49
12	9.03342	116	9.03597	117	0.96403	9.99745	48
13	9.03458	116	9.03714	118	0.96286	9.99744	47
14	9.03574	116	9.03832	116	0.96168	9.99742	46
15	9.03690	115	9.03948	117	0.96052	9.99741	45
16	9.03805	115	9.04065	116	0.95935	9.99740	44
17	9.03920	114	9.04181	116	0.95819	9.99738	43
18	9.04034	115	9.04297	116	0.95703	9.99737	42
19	9.04149	113	9.04413	115	0.95587	9.99736	41
20	9.04262	114	9.04528	115	0.95472	9.99734	40
21	9.04376	114	9.04643	115	0.95357	9.99733	39
22	9.04490	113	9.04758	115	0.95242	9.99731	38
23	9.04603	112	9.04873	114	0.95127	9.99730	37
24	9.04715	113	9.04987	114	0.95013	9.99728	36
25	9.04828	112	9.05101	113	0.94899	9.99727	35
26	9.04940	112	9.05214	114	0.94786	9.99726	34
27	9.05052	112	9.05328	113	0.94672	9.99724	33
28	9.05164	111	9.05441	112	0.94559	9.99723	32
29	9.05275	111	9.05553	113	0.94447	9.99721	31
30	9.05386	111	9.05666	112	0.94334	9.99720	30
31	9.05497	110	9.05778	112	0.94222	9.99718	29
32	9.05607	110	9.05890	112	0.94110	9.99717	28
33	9.05717	110	9.06002	111	0.93998	9.99716	27
34	9.05827	110	9.06113	111	0.93887	9.99714	26
35	9.05937	109	9.06224	111	0.93776	9.99713	25
36	9.06046	109	9.06335	110	0.93665	9.99711	24
37	9.06155	109	9.06445	111	0.93555	9.99710	23
38	9.06264	108	9.06556	110	0.93444	9.99708	22
39	9.06372	109	9.06666	109	0.93334	9.99707	21
40	9.06481	108	9.06775	110	0.93225	9.99705	20
41	9.06589	107	9.06885	109	0.93115	9.99704	19
42	9.06696	108	9.06994	109	0.93006	9.99702	18
43	9.06804	107	9.07103	108	0.92897	9.99701	17
44	9.06911	107	9.07211	109	0.92789	9.99699	16
45	9.07018	106	9.07320	108	0.92680	9.99698	15
46	9.07124	107	9.07428	108	0.92572	9.99696	14
47	9.07231	106	9.07536	107	0.92464	9.99695	13
48	9.07337	105	9.07643	108	0.92357	9.99693	12
49	9.07442	106	9.07751	107	0.92249	9.99692	11
50	9.07548	105	9.07858	106	0.92142	9.99690	10
51	9.07653	105	9.07964	107	0.92036	9.99689	9
52	9.07758	105	9.08071	106	0.91929	9.99687	8
53	9.07863	105	9.08177	106	0.91823	9.99686	7
54	9.07968	104	9.08283	106	0.91717	9.99684	6
55	9.08072	104	9.08389	106	0.91611	9.99683	5
56	9.08176	104	9.08495	105	0.91505	9.99681	4
57	9.08280	103	9.08600	105	0.91400	9.99680	3
58	9.08383	103	9.08705	105	0.91295	9.99678	2
59	9.08486	103	9.08810	104	0.91190	9.99677	1
60	9.08589		9.08914		0.91086	9.99675	0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	′

P. P.

	121	120	119
6	12.1	12.0	11.9
7	14.1	14.0	13.9
8	16.1	16.0	15.9
9	18.2	18.0	17.9
10	20.2	20.0	19.8
20	40.3	40.0	39.7
30	60.5	60.0	59.5
40	80.7	80.0	79.3
50	100.8	100.0	99.2

	118	117	116
6	11.8	11.7	11.6
7	13.8	13.7	13.5
8	15.7	15.6	15.5
9	17.7	17.6	17.4
10	19.7	19.5	19.3
20	39.3	39.0	38.7
30	59.0	58.5	58.0
40	78.7	78.0	77.3
50	98.3	97.5	96.7

	115	114	113
6	11.5	11.4	11.3
7	13.4	13.3	13.2
8	15.3	15.2	15.1
9	17.3	17.1	17.0
10	19.2	19.0	18.8
20	38.3	38.0	37.7
30	57.5	57.0	56.5
40	76.7	76.0	75.3
50	95.8	95.0	94.2

	112	111	110
6	11.2	11.1	11.0
7	13.1	13.0	12.8
8	14.9	14.8	14.7
9	16.8	16.7	16.5
10	18.7	18.5	18.3
20	37.3	37.0	36.7
30	56.0	55.5	55.0
40	74.7	74.0	73.3
50	93.3	92.5	91.7

	109	108	107
6	10.9	10.8	10.7
7	12.7	12.6	12.5
8	14.5	14.4	14.3
9	16.4	16.2	16.1
10	18.2	18.0	17.8
20	36.3	36.0	35.7
30	54.5	54.0	53.5
40	72.7	72.0	71.3
50	90.8	90.0	89.2

	106	105	104
6	10.6	10.5	10.4
7	12.4	12.3	12.1
8	14.1	14.0	13.9
9	15.9	15.8	15.6
10	17.7	17.5	17.3
20	35.3	35.0	34.7
30	53.0	52.5	52.0
40	70.7	70.0	69.3
50	88.3	87.5	86.7

P. P.

83°

7°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	
0	9.08589	103	9.08914	105	0.91086	9.99675	60
1	9.08692	103	9.09019	104	0.90981	9.99674	59
2	9.08795	102	9.09123	104	0.90877	9.99672	58
3	9.08897	102	9.09227	103	0.90773	9.99670	57
4	9.08999	102	9.09330	104	0.90670	9.99669	56
5	9.09101	101	9.09434	103	0.90566	9.99667	55
6	9.09202	102	9.09537	103	0.90463	9.99666	54
7	9.09304	101	9.09640	102	0.90360	9.99664	53
8	9.09405	101	9.09742	103	0.90258	9.99663	52
9	9.09506	100	9.09845	102	0.90155	9.99661	51
10	9.09606	101	9.09947	102	0.90053	9.99659	50
11	9.09707	100	9.10049	101	0.89951	9.99658	49
12	9.09807	100	9.10150	102	0.89850	9.99656	48
13	9.09907	99	9.10252	101	0.89748	9.99655	47
14	9.10006	100	9.10353	101	0.89647	9.99653	46
15	9.10106	99	9.10454	101	0.89546	9.99651	45
16	9.10205	99	9.10555	101	0.89445	9.99650	44
17	9.10304	98	9.10656	100	0.89344	9.99648	43
18	9.10402	99	9.10756	100	0.89244	9.99647	42
19	9.10501	98	9.10856	100	0.89144	9.99645	41
20	9.10599	98	9.10956	100	0.89044	9.99643	40
21	9.10697	98	9.11056	99	0.88944	9.99642	39
22	9.10795	98	9.11155	99	0.88845	9.99640	38
23	9.10893	97	9.11254	99	0.88746	9.99638	37
24	9.10990	97	9.11353	99	0.88647	9.99637	36
25	9.11087	97	9.11452	99	0.88548	9.99635	35
26	9.11184	97	9.11551	98	0.88449	9.99633	34
27	9.11281	96	9.11649	98	0.88351	9.99632	33
28	9.11377	97	9.11747	98	0.88253	9.99630	32
29	9.11474	96	9.11845	98	0.88155	9.99629	31
30	9.11570	96	9.11943	97	0.88057	9.99627	30
31	9.11666	95	9.12040	98	0.87960	9.99625	29
32	9.11761	96	9.12138	97	0.87862	9.99624	28
33	9.11857	95	9.12235	97	0.87765	9.99622	27
34	9.11952	95	9.12332	96	0.87668	9.99620	26
35	9.12047	95	9.12428	97	0.87572	9.99618	25
36	9.12142	94	9.12525	96	0.87475	9.99617	24
37	9.12236	95	9.12621	96	0.87379	9.99615	23
38	9.12331	94	9.12717	96	0.87283	9.99613	22
39	9.12425	94	9.12813	96	0.87187	9.99612	21
40	9.12519	93	9.12909	95	0.87091	9.99610	20
41	9.12612	94	9.13004	95	0.86996	9.99608	19
42	9.12706	93	9.13099	95	0.86901	9.99607	18
43	9.12799	93	9.13194	95	0.86806	9.99605	17
44	9.12892	93	9.13289	95	0.86711	9.99603	16
45	9.12985	93	9.13384	94	0.86616	9.99601	15
46	9.13078	93	9.13478	95	0.86522	9.99600	14
47	9.13171	92	9.13573	94	0.86427	9.99598	13
48	9.13263	92	9.13667	94	0.86333	9.99596	12
49	9.13355	92	9.13761	93	0.86239	9.99595	11
50	9.13447	92	9.13854	94	0.86146	9.99593	10
51	9.13539	91	9.13948	93	0.86052	9.99591	9
52	9.13630	92	9.14041	93	0.85959	9.99589	8
53	9.13722	91	9.14134	93	0.85866	9.99588	7
54	9.13813	91	9.14227	93	0.85773	9.99586	6
55	9.13904	90	9.14320	92	0.85680	9.99584	5
56	9.13994	91	9.14412	92	0.85588	9.99582	4
57	9.14085	90	9.14504	93	0.85496	9.99581	3
58	9.14175	91	9.14597	91	0.85403	9.99579	2
59	9.14266	90	9.14688	92	0.85312	9.99577	1
60	9.14356		9.14780		0.85220	9.99575	0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	′

P. P.

	105	104	103
6	10.5	10.4	10.3
7	12.3	12.1	12.0
8	14.0	13.9	13.7
9	15.8	15.6	15.5
10	17.5	17.3	17.2
20	35.0	34.7	34.3
30	52.5	52.0	51.5
40	70.0	69.3	68.7
50	87.5	86.7	85.8

	102	101	100
6	10.2	10.1	10.0
7	11.9	11.8	11.7
8	13.6	13.5	13.3
9	15.3	15.2	15.0
10	17.0	16.8	16.7
20	34.0	33.7	33.3
30	51.0	50.5	50.0
40	68.0	67.3	66.7
50	85.0	84.2	83.3

	99	98
6	9.9	9.8
7	11.6	11.4
8	13.2	13.1
9	14.9	14.7
10	16.5	16.3
20	33.0	32.7
30	49.5	49.0
40	66.0	65.3
50	82.5	81.7

	97	96	95
6	9.7	9.6	9.5
7	11.3	11.2	11.1
8	12.9	12.8	12.7
9	14.6	14.4	14.3
10	16.2	16.0	15.8
20	32.3	32.0	31.7
30	48.5	48.0	47.5
40	64.7	64.0	63.3
50	80.8	80.0	79.2

	94	93	92
6	9.4	9.3	9.2
7	11.0	10.9	10.7
8	12.5	12.4	12.3
9	14.1	14.0	13.8
10	15.7	15.5	15.3
20	31.3	31.0	30.7
30	47.0	46.5	46.0
40	62.7	62.0	61.3
50	78.3	77.5	76.7

	91	90	2
6	9.1	9.0	0.2
7	10.6	10.5	0.2
8	12.1	12.0	0.3
9	13.7	13.5	0.3
10	15.2	15.0	0.3
20	30.3	30.0	0.7
30	45.5	45.0	1.0
40	60.7	60.0	1.3
50	75.8	75.0	1.7

P. P.

82°

8°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	
0	9.14356	89	9.14780	92	0.85220	9.99575	60
1	9.14445	90	9.14872	91	0.85128	9.99574	59
2	9.14535	89	9.14963	91	0.85037	9.99572	58
3	9.14624	90	9.15054	91	0.84946	9.99570	57
4	9.14714	89	9.15145	91	0.84855	9.99568	56
5	9.14803	88	9.15236	91	0.84764	9.99566	55
6	9.14891	89	9.15327	90	0.84673	9.99565	54
7	9.14980	89	9.15417	91	0.84583	9.99563	53
8	9.15069	88	9.15508	90	0.84492	9.99561	52
9	9.15157	88	9.15598	90	0.84402	9.99559	51
10	9.15245	88	9.15688	89	0.84312	9.99557	50
11	9.15333	88	9.15777	90	0.84223	9.99556	49
12	9.15421	87	9.15867	89	0.84133	9.99554	48
13	9.15508	88	9.15956	90	0.84044	9.99552	47
14	9.15596	87	9.16046	89	0.83954	9.99550	46
15	9.15683	87	9.16135	89	0.83865	9.99548	45
16	9.15770	87	9.16224	88	0.83776	9.99546	44
17	9.15857	87	9.16312	89	0.83688	9.99545	43
18	9.15944	86	9.16401	88	0.83599	9.99543	42
19	9.16030	86	9.16489	88	0.83511	9.99541	41
20	9.16116	87	9.16577	88	0.83423	9.99539	40
21	9.16203	86	9.16665	88	0.83335	9.99537	39
22	9.16289	85	9.16753	88	0.83247	9.99535	38
23	9.16374	86	9.16841	87	0.83159	9.99533	37
24	9.16460	85	9.16928	88	0.83072	9.99532	36
25	9.16545	86	9.17016	87	0.82984	9.99530	35
26	9.16631	85	9.17103	87	0.82897	9.99528	34
27	9.16716	85	9.17190	87	0.82810	9.99526	33
28	9.16801	85	9.17277	86	0.82723	9.99524	32
29	9.16886	84	9.17363	87	0.82637	9.99522	31
30	9.16970	85	9.17450	86	0.82550	9.99520	30
31	9.17055	84	9.17536	86	0.82464	9.99518	29
32	9.17139	84	9.17622	86	0.82378	9.99517	28
33	9.17223	84	9.17708	86	0.82292	9.99515	27
34	9.17307	84	9.17794	86	0.82206	9.99513	26
35	9.17391	83	9.17880	85	0.82120	9.99511	25
36	9.17474	84	9.17965	86	0.82035	9.99509	24
37	9.17558	83	9.18051	85	0.81949	9.99507	23
38	9.17641	83	9.18136	85	0.81864	9.99505	22
39	9.17724	83	9.18221	85	0.81779	9.99503	21
40	9.17807	83	9.18306	85	0.81694	9.99501	20
41	9.17890	83	9.18391	84	0.81609	9.99409	19
42	9.17973	82	9.18475	85	0.81525	9.99497	18
43	9.18055	82	9.18560	84	0.81440	9.99495	17
44	9.18137	83	9.18644	84	0.81356	9.99494	16
45	9.18220	82	9.18728	84	0.81272	9.99492	15
46	9.18302	81	9.18812	84	0.81188	9.99490	14
47	9.18383	82	9.18896	83	0.81104	9.99488	13
48	9.18465	82	9.18979	84	0.81021	9.99486	12
49	9.18547	81	9.19063	83	0.80937	9.99484	11
50	9.18628	81	9.19146	83	0.80854	9.99482	10
51	9.18709	81	9.19229	83	0.80771	9.99480	9
52	9.18790	81	9.19312	83	0.80688	9.99478	8
53	9.18871	81	9.19395	83	0.80605	9.99476	7
54	9.18952	81	9.19478	83	0.80522	9.99474	6
55	9.19033	80	9.19561	82	0.80439	9.99472	5
56	9.19113	80	9.19643	82	0.80357	9.99470	4
57	9.19193	80	9.19725	82	0.80275	9.99468	3
58	9.19273	80	9.19807	82	0.80193	9.99466	2
59	9.19353	80	9.19889	82	0.80111	9.99464	1
60	9.19433		9.19971		0.80029	9.99462	0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	′

P. P.

	92	91	90
6	9.2	9.1	9.0
7	10.7	10.6	10.5
8	12.3	12.1	12.0
9	13.8	13.7	13.5
10	15.3	15.2	15.0
20	30.7	30.3	30.0
30	46.0	45.5	45.0
40	61.3	60.7	60.0
50	76.7	75.8	75.0

	89	88
6	8.9	8.8
7	10.4	10.3
8	11.9	11.7
9	13.4	13.2
10	14.8	14.7
20	20.7	29.3
30	44.5	44.0
40	59.3	58.7
50	74.2	73.3

	87	86
6	8.7	8.6
7	10.2	10.0
8	11.6	11.5
9	13.1	12.9
10	14.5	14.3
20	29.0	28.7
30	43.5	43.0
40	58.0	57.3
50	72.5	71.7

	85	84
6	8.5	8.4
7	9.9	9.8
8	11.3	11.2
9	12.8	12.6
10	14.2	14.0
20	28.3	28.0
30	42.5	42.0
40	56.7	56.0
50	70.8	70.0

	83	82
6	8.3	8.2
7	9.7	9.6
8	11.1	10.9
9	12.5	12.3
10	13.8	13.7
20	27.7	27.3
30	41.5	41.0
40	55.3	54.7
50	69.2	68.3

	81	80	2
6	8.1	8.0	0.2
7	9.5	9.3	0.2
8	10.8	10.7	0.3
9	12.2	12.0	0.3
10	13.5	13.3	0.3
20	27.0	26.7	0.7
30	40.5	40.0	1.0
40	54.0	53.3	1.3
50	67.5	66.7	1.7

P. P.

81°

9°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	
0	9.19433	80	9.19971	82	0.80029	9.99462	**60**
1	9.19513	79	9.20053	81	0.79947	9.99460	59
2	9.19592	80	9.20134	82	0.79866	9.99458	58
3	9.19672	79	9.20216	81	0.79784	9.99456	57
4	9.19751	79	9.20297	81	0.79703	9.99454	56
5	9.19830	79	9.20378	81	0.79622	9.99452	55
6	9.19909	79	9.20459	81	0.79541	9.99450	54
7	9.19988	79	9.20540	81	0.79460	9.99448	53
8	9.20067	78	9.20621	80	0.79379	9.99446	52
9	9.20145	78	9.20701	81	0.79299	9 99444	51
10	9.20223	79	9.20782	80	0.79218	9.99442	**50**
11	9.20302	78	9.20862	80	0.79138	9.99440	49
12	9.20380	78	9.20942	80	0.79058	9.99438	48
13	9.20458	77	9.21022	80	0.78978	9.99436	47
14	9.20535	78	9.21102	80	0.78898	9.99434	46
15	9.20613	78	9.21182	79	0.78818	9.99432	45
16	9.20691	77	9.21261	80	0.78739	9.99429	44
17	9.20768	77	9.21341	79	0.78659	9.99427	43
18	9.20845	77	9.21420	79	0.78580	9.99425	42
19	9.20922	77	9.21499	79	0.78501	9.99423	41
20	9.20999	77	9.21578	79	0.78422	9.99421	**40**
21	9.21076	77	9.21657	79	0.78343	9.99419	39
22	9.21153	76	9.21736	78	0.78264	9.99417	38
23	9.21229	77	9.21814	79	0.78186	9.99415	37
24	9.21306	76	9.21893	78	0.78107	9.99413	36
25	9.21382	76	9.21971	78	0.78029	9.99411	35
26	9.21458	76	9.22049	78	0.77951	9.99409	34
27	9.21534	76	9.22127	78	0.77873	9.99407	33
28	9.21610	75	9.22205	78	0.77795	9.99404	32
29	9.21685	76	9.22283	78	0.77717	9.99402	31
30	9.21761	75	9.22361	77	0.77639	9.99400	**30**
31	9.21836	76	9.22438	78	0.77562	9.99398	29
32	9.21912	75	9.22516	77	0.77484	9.99396	28
33	9.21987	75	9.22593	77	0.77407	9.99394	27
34	9.22062	75	9.22670	77	0.77330	9.99392	26
35	9.22137	74	9.22747	77	0.77253	9.99390	25
36	9.22211	75	9.22824	77	0.77176	9.99388	24
37	9.22286	75	9.22901	76	0.77099	9.99385	23
38	9.22361	74	9.22977	77	0.77023	9.99383	22
39	9.22435	74	9.23054	76	0.76946	9.99381	21
40	9.22509	74	9.23130	76	0.76870	9.99379	**20**
41	9.22583	74	9.23206	77	0.76794	9.99377	19
42	9.22657	74	9.23283	76	0.76717	9.99375	18
43	9.22731	74	9.23359	76	0.76641	9.99372	17
44	9.22805	73	9.23435	75	0.76565	9.99370	16
45	9.22878	74	9.23510	76	0.76490	9.99368	15
46	9.22952	73	9.23586	75	0.76414	9.99366	14
47	9.23025	73	9.23661	76	0.76339	9.99364	13
48	9.23098	73	9.23737	75	0.76263	9.99362	12
49	9.23171	73	9.23812	75	0.76188	9.99359	11
50	9.23244	73	9.23887	75	0.76113	9.99357	**10**
51	9.23317	73	9.23962	75	0.76038	9.99355	9
52	9.23390	72	9.24037	75	0.75963	9.99353	8
53	9.23462	73	9.24112	74	0.75888	9.99351	7
54	9.23535	72	9.24186	75	0.75814	9.99348	6
55	9.23607	72	9.24261	74	0.75739	9.99346	5
56	9.23679	73	9.24335	75	0.75665	9.99344	4
57	9.23752	71	9.24410	74	0.75590	9.99342	3
58	9.23823	72	9.24484	74	0.75516	9.99340	2
59	9.23895	72	9.24558	74	0.75442	9.99337	1
60	9.23967		9.24632		0.75368	9.99335	**0**
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	′

P. P.

	82	81	80
6	8.2	8.1	8.0
7	9.6	9.5	9.3
8	10.9	10.8	10.7
9	12.3	12.2	12.0
10	13.7	13.5	13.3
20	27.3	27.0	26.7
30	41.0	40.5	40.0
40	54.7	54.0	53.3
50	68.3	67.5	66.7

	79	78
6	7.9	7.8
7	9.2	9.1
8	10.5	10.4
9	11.9	11.7
10	13.2	13.0
20	26.3	26.0
30	39.5	39.0
40	52.7	52.0
50	65.8	65.0

	77	76
6	7.7	7.6
7	9.0	8.9
8	10.3	10.1
9	11.6	11.4
10	12.8	12.7
20	25.7	25.3
30	38.5	38.0
40	51.3	50.7
50	64.2	63.3

	75	74
6	7.5	7.4
7	8.8	8.6
8	10.0	9.9
9	11.3	11.1
10	12.5	12.3
20	25.0	24.7
30	37.5	37.0
40	50.0	49.3
50	62.5	61.7

	73	72
6	7.3	7.2
7	8.5	8.4
8	9.7	9.6
9	11.0	10.8
10	12.2	12.0
20	24.3	24.0
30	36.5	36.0
40	48.7	48.0
50	60.8	60.0

	71	3	2
6	7.1	0.3	0.2
7	8.3	0.4	0.2
8	9.5	0.4	0.3
9	10.7	0.5	0.3
10	11.8	0.5	0.3
20	23.7	1.0	0.7
30	35.5	1.5	1.0
40	47.3	2.0	1.3
50	59.2	2.5	1.7

P. P.

80°

10°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	
0	9.23967	72	9.24632	74	0.75368	9.99335	60
1	9.24039	71	9.24706	73	0.75294	9.99333	59
2	9.24110	71	9.24779	74	0.75221	9.99331	58
3	9.24181	72	9.24853	73	0.75147	9.99328	57
4	9.24253	71	9.24926	74	0.75074	9.99326	56
5	9.24324	71	9.25000	73	0.75000	9.99324	55
6	9.24395	71	9.25073	73	0.74927	9.99322	54
7	9.24466	70	9.25146	73	0.74854	9.99319	53
8	9.24536	71	9.25219	73	0.74781	9.99317	52
9	9.24607	70	9.25292	73	0.74708	9.99315	51
10	9.24677	71	9.25365	72	0.74635	9.99313	50
11	9.24748	70	9.25437	73	0.74563	9.99310	49
12	9.24818	70	9.25510	72	0.74490	9.99308	48
13	9.24888	70	9.25582	73	0.74418	9.99306	47
14	9.24958	70	9.25655	72	0.74345	9.99304	46
15	9.25028	70	9.25727	72	0.74273	9.99301	45
16	9.25098	70	9.25799	72	0.74201	9.99299	44
17	9.25168	69	9.25871	72	0.74129	9.99297	43
18	9.25237	70	9.25943	72	0.74057	9.99294	42
19	9.25307	69	9.26015	71	0.73985	9.99292	41
20	9.25376	69	9.26086	72	0.73914	9.99290	40
21	9.25445	69	9.26158	71	0.73842	9.99288	39
22	9.25514	69	9.26229	72	0.73771	9.99285	38
23	9.25583	69	9.26301	71	0.73699	9.99283	37
24	9.25652	69	9.26372	71	0.73628	9.99281	36
25	9.25721	69	9.26443	71	0.73557	9.99278	35
26	9.25790	68	9.26514	71	0.73486	9.99276	34
27	9.25858	69	9.26585	70	0.73415	9.99274	33
28	9.25927	68	9.26655	71	0.73345	9.99271	32
29	9.25995	68	9.26726	71	0.73274	9.99269	31
30	9.26063	68	9.26797	70	0.73203	9.99267	30
31	9.26131	68	9.26867	70	0.73133	9.99264	29
32	9.26199	68	9.26937	71	0.73063	9.99262	28
33	9.26267	68	9.27008	70	0.72992	9.99260	27
34	9.26335	68	9.27078	70	0.72922	9.99257	26
35	9.26403	67	9.27148	70	0.72852	9.99255	25
36	9.26470	68	9.27218	70	0.72782	9.99252	24
37	9.26538	67	9.27288	69	0.72712	9.99250	23
38	9.26605	67	9.27357	70	0.72643	9.99248	22
39	9.26672	67	9.27427	69	0.72573	9.99245	21
40	9.26739	67	9.27496	70	0.72504	9.99243	20
41	9.26806	67	9.27566	69	0.72434	9.99241	19
42	9.26873	67	9.27635	69	0.72365	9.99238	18
43	9.26940	67	9.27704	69	0.72296	9.99236	17
44	9.27007	66	9.27773	69	0.72227	9.99233	16
45	9.27073	67	9.27842	69	0.72158	9.99231	15
46	9.27140	66	9.27911	69	0.72089	9.99229	14
47	9.27206	67	9.27980	69	0.72020	9.99226	13
48	9.27273	66	9.28049	68	0.71951	9.99224	12
49	9.27339	66	9.28117	69	0.71883	9.99221	11
50	9.27405	66	9.28186	68	0.71814	9.99219	10
51	9.27471	66	9.28254	69	0.71746	9.99217	9
52	9.27537	65	9.28323	68	0.71677	9.99214	8
53	9.27602	66	9.28391	68	0.71609	9.99212	7
54	9.27668	66	9.28459	68	0.71541	9.99209	6
55	9.27734	65	9.28527	68	0.71473	9.99207	5
56	9.27799	65	9.28595	67	0.71405	9.99204	4
57	9.27864	66	9.28662	68	0.71338	9.99202	3
58	9.27930	65	9.28730	68	0.71270	9.99200	2
59	9.27995	65	9.28798	67	0.71202	9.99197	1
60	9.28060		9.28865		0.71135	9.99195	0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	′

P. P.

	74	73	72	71	70	69	68	67	66	65	3	2
6	7.4	7.3	7.2	7.1	7.0	6.9	6.8	6.7	6.6	6.5	0.3	0.2
7	8.6	8.5	8.4	8.3	8.2	8.1	7.9	7.8	7.7	7.6	0.4	0.2
8	9.9	9.7	9.6	9.5	9.3	9.2	9.1	8.9	8.8	8.7	0.4	0.3
9	11.1	11.0	10.8	10.7	10.5	10.4	10.2	10.1	9.9	9.8	0.5	0.3
10	12.3	12.2	12.0	11.8	11.7	11.5	11.3	11.2	11.0	10.8	0.5	0.3
20	24.7	24.3	24.0	23.7	23.3	23.0	22.7	22.3	22.0	21.7		
10											1.0	0.7
30	37.0	36.5	36.0	35.5	35.0	34.5	34.0	33.5	33.0	32.5	1.5	1.0
40	49.3	48.7	48.0	47.3	46.7	46.0	45.3	44.7	44.0	43.3	2.0	1.3
50	61.7	60.8	60.0	59.2	58.3	57.5	56.7	55.8	55.0	54.2	2.5	1.7

P. P.

79°

11°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	
0	9.28060	65	9.28865	68	0.71135	9.99195	60
1	9.28125	65	9.28933	67	0.71067	9.99192	59
2	9.28190	64	9.29000	67	0.71000	9.99190	58
3	9.28254	65	9.29067	67	0.70933	9.99187	57
4	9.28319	65	9.29134	67	0.70866	9.99185	56
5	9.28384	64	9.29201	67	0.70799	9.99182	55
6	9.28448	64	9.29268	67	0.70732	9.99180	54
7	9.28512	65	9.29335	67	0.70665	9.99177	53
8	9.28577	64	9.29402	66	0.70598	9.99175	52
9	9.28641	64	9.29468	67	0.70532	9.99172	51
10	9.28705	64	9.29535	66	0.70465	9.99170	50
11	9.28769	64	9.29601	67	0.70399	9.99167	49
12	9.28833	63	9.29668	66	0.70332	9.99165	48
13	9.28896	64	9.29734	66	0.70266	9.99162	47
14	9.28960	64	9.29800	66	0.70200	9.99160	46
15	9.29024	63	9.29866	66	0.70134	9.99157	45
16	9.29087	63	9.29932	66	0.70068	9.99155	44
17	9.29150	64	9.29998	66	0.70002	9.99152	43
18	9.29214	63	9.30064	66	0.69936	9.99150	42
19	9.29277	63	9.30130	65	0.69870	9.99147	41
20	9.29340	63	9.30195	66	0.69805	9.99145	40
21	9.29403	63	9.30261	65	0.69739	9.99142	39
22	9.29466	63	9.30326	65	0.69674	9.99140	38
23	9.29529	62	9.30391	66	0.69609	9.99137	37
24	9.29591	63	9.30457	65	0.69543	9.99135	36
25	9.29654	62	9.30522	65	0.69478	9.99132	35
26	9.29716	63	9.30587	65	0.69413	9.99130	34
27	9.29779	62	9.30652	65	0.69348	9.99127	33
28	9.29841	62	9.30717	65	0.69283	9.99124	32
29	9.29903	63	9.30782	64	0.69218	9.99122	31
30	9.29966	62	9.30846	65	0.69154	9.99119	30
31	9.30028	62	9.30911	64	0.69089	9.99117	29
32	9.30090	61	9.30975	65	0.69025	9.99114	28
33	9.30151	62	9.31040	64	0.68960	9.99112	27
34	9.30213	62	9.31104	64	0.68896	9.99109	26
35	9.30275	61	9.31168	65	0.68832	9.99106	25
36	9.30336	62	9.31233	64	0.68767	9.99104	24
37	9.30398	61	9.31297	64	0.68703	9.99101	23
38	9.30459	62	9.31361	64	0.68639	9.99099	22
39	9.30521	61	9.31425	64	0.68575	9.99096	21
40	9.30582	61	9.31489	63	0.68511	9.99093	20
41	9.30643	61	9.31552	64	0.68448	9.99091	19
42	9.30704	61	9.31616	63	0.68384	9.99088	18
43	9.30765	61	9.31679	64	0.68321	9.99086	17
44	9.30826	61	9.31743	63	0.68257	9.99083	16
45	9.30887	60	9.31806	64	0.68194	9.99080	15
46	9.30947	61	9.31870	63	0.68130	9.99078	14
47	9.31008	60	9.31933	63	0.68067	9.99075	13
48	9.31068	61	9.31996	63	0.68004	9.99072	12
49	9.31129	60	9.32059	63	0.67941	9.99070	11
50	9.31189	61	9.32122	63	0.67878	9.99067	10
51	9.31250	60	9.32185	63	0.67815	9.99064	9
52	9.31310	60	9.32248	63	0.67752	9.99062	8
53	9.31370	60	9.32311	62	0.67689	9.99059	7
54	9.31430	60	9.32373	63	0.67627	9.99056	6
55	9.31490	59	9.32436	62	0.67564	9.99054	5
56	9.31549	60	9.32498	63	0.67502	9.99051	4
57	9.31609	60	9.32561	62	0.67439	9.99048	3
58	9.31669	59	9.32623	62	0.67377	9.99046	2
59	9.31728	60	9.32685	62	0.67315	9.99043	1
60	9.31788		9.32747		0.67253	9.99040	0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	′

P. P.

	68	67	66	65	64	63	62	61	60	59	3	2
6	6.8	6.7	6.6	6.5	6.4	6.3	6.2	6.1	6.0	5.9	0.3	0.2
7	7.9	7.8	7.7	7.6	7.5	7.4	7.2	7.1	7.0	6.9	0.4	0.2
8	9.1	8.9	8.8	8.7	8.5	8.4	8.3	8.1	8.0	7.9	0.4	0.3
9	10.2	10.1	9.9	9.8	9.6	9.5	9.3	9.2	9.0	8.9	0.5	0.3
10	11.3	11.2	11.0	10.8	10.7	10.5	10.3	10.2	10.0	9.8	0.5	0.3
20	22.7	22.3	22.0	21.7	21.3	21.0	20.7	20.3	20.0	19.7	1.0	0.7
30	34.0	33.5	33.0	32.5	32.0	31.5	31.0	30.5	30.0	29.5	1.5	1.0
40	45.3	44.7	44.0	43.3	42.7	42.0	41.3	40.7	40.0	39.3	2.0	1.3
50	56.7	55.8	55.0	54.2	53.3	52.5	51.7	50.8	50.0	49.2	2.5	1.7

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12°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	
0	9.31788	59	9.32747	63	0.67253	9.99040	60
1	9.31847	60	9.32810	62	0.67190	9.99038	59
2	9.31907	59	9.32872	61	0.67128	9.99035	58
3	9.31966	59	9.32933	62	0.67067	9.99032	57
4	9.32025	59	9.32995	62	0.67005	9.99030	56
5	9.32084	59	9.33057	62	0.66943	9.99027	55
6	9.32143	59	9.33119	61	0.66881	9.99024	54
7	9.32202	59	9.33180	62	0.66820	9.99022	53
8	9.32261	58	9.33242	61	0.66758	9.99019	52
9	9.32319	59	9.33303	62	0.66697	9.99016	51
10	9.32378	59	9.33365	61	0.66635	9.99013	50
11	9.32437	58	9.33426	61	0.66574	9.99011	49
12	9.32495	58	9.33487	61	0.66513	9.99008	48
13	9.32553	59	9.33548	61	0.66452	9.99005	47
14	9.32612	58	9.33609	61	0.66391	9.99002	46
15	9.32670	58	9.33670	61	0.66330	9.99000	45
16	9.32728	58	9.33731	61	0.66269	9.98997	44
17	9.32786	58	9.33792	61	0.66208	9.98994	43
18	9.32844	58	9.33853	60	0.66147	9.98991	42
19	9.32902	58	9.33913	61	0.66087	9.98989	41
20	9.32960	58	9.33974	60	0.66026	9.98986	40
21	9.33018	57	9.34034	61	0.65966	9.98983	39
22	9.33075	58	9.34095	60	0.65905	9.98980	38
23	9.33133	57	9.34155	60	0.65845	9.98978	37
24	9.33190	58	9.34215	61	0.65785	9.98975	36
25	9.33248	57	9.34276	60	0.65724	9.98972	35
26	9.33305	57	9.34336	60	0.65664	9.98969	34
27	9.33362	58	9.34396	60	0.65604	9.98967	33
28	9.33420	57	9.34456	60	0.65544	9.98964	32
29	9.33477	57	9.34516	60	0.65484	9.98961	31
30	9.33534	57	9.34576	59	0.65424	9.98958	30
31	9.33591	56	9.34635	60	0.65365	9.98955	29
32	9.33647	57	9.34695	60	0.65305	9.98953	28
33	9.33704	57	9.34755	59	0.65245	9.98950	27
34	9.33761	57	9.34814	60	0.65186	9.98947	26
35	9.33818	56	9.34874	59	0.65126	9.98944	25
36	9.33874	57	9.34933	59	0.65067	9.98941	24
37	9.33931	56	9.34992	59	0.65008	9.98938	23
38	9.33987	56	9.35051	60	0.64949	9.98936	22
39	9.34043	57	9.35111	59	0.64889	9.98933	21
40	9.34100	56	9.35170	59	0.64830	9.98930	20
41	9.34156	56	9.35229	59	0.64771	9.98927	19
42	9.34212	56	9.35288	59	0.64712	9.98924	18
43	9.34268	56	9.35347	58	0.64653	9.98921	17
44	9.34324	56	9.35405	59	0.64595	9.98919	16
45	9.34380	56	9.35464	59	0.64536	9.98916	15
46	9.34436	55	9.35523	58	0.64477	9.98913	14
47	9.34491	56	9.35581	59	0.64419	9.98910	13
48	9.34547	55	9.35640	58	0.64360	9.98907	12
49	9.34602	56	9.35698	59	0.64302	9.98904	11
50	9.34658	55	9.35757	58	0.64243	9.98901	10
51	9.34713	56	9.35815	58	0.64185	9.98898	9
52	9.34769	55	9.35873	58	0.64127	9.98896	8
53	9.34824	55	9.35931	58	0.64069	9.98893	7
54	9.34879	55	9.35989	58	0.64011	9.98890	6
55	9.34934	55	9.36047	58	0.63953	9.98887	5
56	9.34989	55	9.36105	58	0.63895	9.98884	4
57	9.35044	55	9.36163	58	0.63837	9.98881	3
58	9.35099	55	9.36221	58	0.63779	9.98878	2
59	9.35154	55	9.36279	57	0.63721	9.98875	1
60	9.35209		9.36336		0.63664	9.98872	0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	′

P. P.

	63	62	61	60	59	58	57	56	55	3	2
6	6.3	6.2	6.1	6.0	5.9	5.8	5.7	5.6	5.5	0.3	0.2
7	7.4	7.2	7.1	7.0	6.9	6.8	6.7	6.5	6.4	0.4	0.2
8	8.4	8.3	8.1	8.0	7.9	7.7	7.6	7.5	7.3	0.4	0.3
9	9.5	9.3	9.2	9.0	8.9	8.7	8.6	8.4	8.3	0.5	0.3
10	10.5	10.3	10.2	10.0	9.8	9.7	9.5	9.3	9.2	0.5	0.3
20	21.0	20.7	20.3	20.0	19.7	19.3	19.0	18.7	18.3	1.0	0.7
30	31.5	31.0	30.5	30.0	29.5	29.0	28.5	28.0	27.5	1.5	1.0
40	42.0	41.3	40.7	40.0	39.3	38.7	38.0	37.3	36.7	2.0	1.3
50	52.5	51.7	50.8	50.0	49.2	48.3	47.5	46.7	45.8	2.5	1.7

P. P.

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13°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	
0	9.35209	54	9.36336	58	0.63664	9.98872	60
1	9.35263	55	9.36394	58	0.63606	9.98869	59
2	9.35318	55	9.36452	57	0.63548	9.98867	58
3	9.35373	54	9.36509	57	0.63491	9.98864	57
4	9.35427	54	9.36566	58	0.63434	9.98861	56
5	9.35481	55	9.36624	57	0.63376	9.98858	55
6	9.35536	54	9.36681	57	0.63319	9.98855	54
7	9.35590	54	9.36738	57	0.63262	9.98852	53
8	9.35644	54	9.36795	57	0.63205	9.98849	52
9	9.35698	54	9.36852	57	0.63148	9.98846	51
10	9.35752	54	9.36909	57	0.63091	9.98843	50
11	9.35806	54	9.36966	57	0.63034	9.98840	49
12	9.35860	54	9.37023	57	0.62977	9.98837	48
13	9.35914	54	9.37080	57	0.62920	9.98834	47
14	9.35968	54	9.37137	56	0.62863	9.98831	46
15	9.36022	53	9.37193	57	0.62807	9.98828	45
16	9.36075	54	9.37250	56	0.62750	9.98825	44
17	9.36129	53	9.37306	57	0.62694	9.98822	43
18	9.36182	54	9.37363	56	0.62637	9.98819	42
19	9.36236	53	9.37419	57	0.62581	9.98816	41
20	9.36289	53	9.37476	56	0.62524	9.98813	40
21	9.36342	53	9.37532	56	0.62468	9.98810	39
22	9.36395	54	9.37588	56	0.62412	9.98807	38
23	9.36449	53	9.37644	56	0.62356	9.98804	37
24	9.36502	53	9.37700	56	0.62300	9.98801	36
25	9.36555	53	9.37756	56	0.62244	9.98798	35
26	9.36608	52	9.37812	56	0.62188	9.98795	34
27	9.36660	53	9.37868	56	0.62132	9.98792	33
28	9.36713	53	9.37924	56	0.62076	9.98789	32
29	9.36766	53	9.37980	55	0.62020	9.98786	31
30	9.36819	52	9.38035	56	0.61965	9.98783	30
31	9.36871	53	9.38091	56	0.61909	9.98780	29
32	9.36924	52	9.38147	55	0.61853	9.98777	28
33	9.36976	52	9.38202	55	0.61798	9.98774	27
34	9.37028	53	9.38257	56	0.61743	9.98771	26
35	9.37081	52	9.38313	55	0.61687	9.98768	25
36	9.37133	52	9.38368	55	0.61632	9.98765	24
37	9.37185	52	9.38423	56	0.61577	9.98762	23
38	9.37237	52	9.38479	55	0.61521	9.98759	22
39	9.37289	52	9.38534	55	0.61466	9.98756	21
40	9.37341	52	9.38589	55	0.61411	9.98753	20
41	9.37393	52	9.38644	55	0.61356	9.98750	19
42	9.37445	52	9.38699	55	0.61301	9.98746	18
43	9.37497	52	9.38754	54	0.61246	9.98743	17
44	9.37549	51	9.38808	55	0.61192	9.98740	16
45	9.37600	52	9.38863	55	0.61137	9.98737	15
46	9.37652	51	9.38918	54	0.61082	9.98734	14
47	9.37703	52	9.38972	55	0.61028	9.98731	13
48	9.37755	51	9.39027	55	0.60973	9.98728	12
49	9.37806	52	9.39082	54	0.60918	9.98725	11
50	9.37858	51	9.39136	54	0.60864	9.98722	10
51	9.37909	51	9.39190	55	0.60810	9.98719	9
52	9.37960	51	9.39245	54	0.60755	9.98715	8
53	9.38011	51	9.39299	54	0.60701	9.98712	7
54	9.38062	51	9.39353	54	0.60647	9.98709	6
55	9.38113	51	9.39407	54	0.60593	9.98706	5
56	9.38164	51	9.39461	54	0.60539	9.98703	4
57	9.38215	51	9.39515	54	0.60485	9.98700	3
58	9.38266	51	9.39569	54	0.60431	9.98697	2
59	9.38317	51	9.39623	54	0.60377	9.98694	1
60	9.38368		9.39677		0.60323	9.98690	0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	′

76°

P. P.

	58	57
6	5.8	5.7
7	6.8	6.7
8	7.7	7.6
9	8.7	8.6
10	9.7	9.5
20	19.3	19.0
30	29.0	28.5
40	38.7	38.0
50	48.3	47.5

	56	55
6	5.6	5.5
7	6.5	6.4
8	7.5	7.3
9	8.4	8.3
10	9.3	9.2
20	18.7	18.3
30	28.0	27.5
40	37.3	36.7
50	46.7	45.8

	54
6	5.4
7	6.3
8	7.2
9	8.1
10	9.0
20	18.0
30	27.0
40	36.0
50	45.0

	53	52
6	5.3	5.2
7	6.2	6.1
8	7.1	6.9
9	8.0	7.8
10	8.8	8.7
20	17.7	17.3
30	26.5	26.0
40	35.3	34.7
50	44.2	43.3

	51	4
6	5.1	0.4
7	6.0	0.5
8	6.8	0.5
9	7.7	0.6
10	8.5	0.7
20	17.0	1.3
30	25.5	2.0
40	34.0	2.7
50	42.5	3.3

	3	2
6	0.3	0.2
7	0.4	0.2
8	0.4	0.3
9	0.5	0.3
10	0.5	0.3
20	1.0	0.7
30	1.5	1.0
40	2.0	1.3
50	2.5	1.7

P. P.

14°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.38368	50	9.39677	54	0.60323	9.98690	3	60
1	9.38418	51	9.39731	54	0.60269	9.98687	3	59
2	9.38469	50	9.39785	53	0.60215	9.98684	3	58
3	9.38519	51	9.39838	54	0.60162	9.98681	3	57
4	9.38570	50	9.39892	53	0.60108	9.98678	3	56
5	9.38620	50	9.39945	54	0.60055	9.98675	4	55
6	9.38670	51	9.39999	53	0.60001	9.98671	3	54
7	9.38721	50	9.40052	54	0.59948	9.98668	3	53
8	9.38771	50	9.40106	53	0.59894	9.98665	3	52
9	9.38821	50	9.40159	53	0.59841	9.98662	3	51
10	9.38871	50	9.40212	54	0.59788	9.98659	3	50
11	9.38921	50	9.40266	53	0.59734	9.98656	4	49
12	9.38971	50	9.40319	53	0.59681	9.98652	3	48
13	9.39021	50	9.40372	53	0.59628	9.98649	3	47
14	9.39071	50	9.40425	53	0.59575	9.98646	3	46
15	9.39121	49	9.40478	53	0.59522	9.98643	3	45
16	9.39170	50	9.40531	53	0.59469	9.98640	4	44
17	9.39220	50	9.40584	52	0.59416	9.98636	3	43
18	9.39270	49	9.40636	53	0.59364	9.98633	3	42
19	9.39319	50	9.40689	53	0.59311	9.98630	3	41
20	9.39369	49	9.40742	53	0.59258	9.98627	4	40
21	9.39418	49	9.40795	52	0.59205	9.98623	3	39
22	9.39467	50	9.40847	53	0.59153	9.98620	3	38
23	9.39517	49	9.40900	52	0.59100	9.98617	3	37
24	9.39566	49	9.40952	53	0.59048	9.98614	4	36
25	9.39615	49	9.41005	52	0.58995	9.98610	3	35
26	9.39664	49	9.41057	52	0.58943	9.98607	3	34
27	9.39713	49	9.41109	52	0.58891	9.98604	3	33
28	9.39762	49	9.41161	53	0.58839	9.98601	4	32
29	9.39811	49	9.41214	52	0.58786	9.98597	3	31
30	9.39860	49	9.41266	52	0.58734	9.98594	3	30
31	9.39909	49	9.41318	52	0.58682	9.98591	3	29
32	9.39958	48	9.41370	52	0.58630	9.98588	4	28
33	9.40006	49	9.41422	52	0.58578	9.98584	3	27
34	9.40055	48	9.41474	52	0.58526	9.98581	3	26
35	9.40103	49	9.41526	52	0.58474	9.98578	4	25
36	9.40152	48	9.41578	51	0.58422	9.98574	3	24
37	9.40200	49	9.41629	52	0.58371	9.98571	3	23
38	9.40249	48	9.41681	52	0.58319	9.98568	3	22
39	9.40297	49	9.41733	51	0.58267	9.98565	4	21
40	9.40346	48	9.41784	52	0.58216	9.98561	3	20
41	9.40394	48	9.41836	51	0.58164	9.98558	3	19
42	9.40442	48	9.41887	52	0.58113	9.98555	4	18
43	9.40490	48	9.41939	51	0.58061	9.98551	3	17
44	9.40538	48	9.41990	51	0.58010	9.98548	3	16
45	9.40586	48	9.42041	52	0.57959	9.98545	4	15
46	9.40634	48	9.42093	51	0.57907	9.98541	3	14
47	9.40682	48	9.42144	51	0.57856	9.98538	3	13
48	9.40730	48	9.42195	51	0.57805	9.98535	4	12
49	9.40778	47	9.42246	51	0.57754	9.98531	3	11
50	9.40825	48	9.42297	51	0.57703	9.98528	3	10
51	9.40873	48	9.42348	51	0.57652	9.98525	4	9
52	9.40921	47	9.42399	51	0.57601	9.98521	3	8
53	9.40968	48	9.42450	51	0.57550	9.98518	3	7
54	9.41016	47	9.42501	51	0.57499	9.98515	4	6
55	9.41063	48	9.42552	51	0.57448	9.98511	3	5
56	9.41111	47	9.42603	50	0.57397	9.98508	3	4
57	9.41158	47	9.42653	51	0.57347	9.98505	4	3
58	9.41205	47	9.42704	51	0.57296	9.98501	3	2
59	9.41252	48	9.42755	50	0.57245	9.98498	4	1
60	9.41300		9.42805		0.57195	9.98494		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

P. P.

	54	53
6	5.4	5.3
7	6.3	6.2
8	7.2	7.1
9	8.1	8.0
10	9.0	8.8
20	18.0	17.7
30	27.0	26.5
40	36.0	35.3
50	45.0	44.2

	52	51
6	5.2	5.1
7	6.1	6.0
8	6.9	6.8
9	7.8	7.7
10	8.7	8.5
20	17.3	17.0
30	26.0	25.5
40	34.7	34.0
50	43.3	42.5

	50	49
6	5.0	4.9
7	5.8	5.7
8	6.7	6.5
9	7.5	7.4
10	8.3	8.2
20	16.7	16.3
30	25.0	24.5
40	33.3	32.7
50	41.7	40.8

	48	47
6	4.8	4.7
7	5.6	5.5
8	6.4	6.3
9	7.2	7.1
10	8.0	7.8
20	16.0	15.7
30	24.0	23.5
40	32.0	31.3
50	40.0	39.2

	4	3
6	0.4	0.3
7	0.5	0.4
8	0.5	0.4
9	0.6	0.5
10	0.7	0.5
20	1.3	1.0
30	2.0	1.5
40	2.7	2.0
50	3.3	2.5

P. P.

75°

15°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.41300	47	9.42805	51	0.57195	9.98494	3	60
1	9.41347	47	9.42856	50	0.57144	9.98491	3	59
2	9.41394	47	9.42906	51	0.57094	9.98488	4	58
3	9.41441	47	9.42957	50	0.57043	9.98484	3	57
4	9.41488	47	9.43007	50	0.56993	9.98481	4	56
5	9.41535	47	9.43057	51	0.56943	9.98477	3	55
6	9.41582	46	9.43108	50	0.56892	9.98474	3	54
7	9.41628	47	9.43158	50	0.56842	9.98471	4	53
8	9.41675	47	9.43208	50	0.56792	9.98467	3	52
9	9.41722	46	9.43258	50	0.56742	9.98464	4	51
10	9.41768	47	9.43308	50	0.56692	9.98460	3	50
11	9.41815	46	9.43358	50	0.56642	9.98457	4	49
12	9.41861	47	9.43408	50	0.56592	9.98453	3	48
13	9.41908	46	9.43458	50	0.56542	9.98450	3	47
14	9.41954	47	9.43508	50	0.56492	9.98447	4	46
15	9.42001	46	9.43558	49	0.56442	9.98443	3	45
16	9.42047	46	9.43607	50	0.56393	9.98440	4	44
17	9.42093	47	9.43657	50	0.56343	9.98436	3	43
18	9.42140	46	9.43707	49	0.56293	9.98433	4	42
19	9.42186	46	9.43756	50	0.56244	9.98429	3	41
20	9.42232	46	9.43806	49	0.56194	9.98426	4	40
21	9.42278	46	9.43855	50	0.56145	9.98422	3	39
22	9.42324	46	9.43905	49	0.56095	9.98419	4	38
23	9.42370	46	9.43954	50	0.56046	9.98415	3	37
24	9.42416	45	9.44004	49	0.55996	9.98412	3	36
25	9.42461	46	9.44053	49	0.55947	9.98409	4	35
26	9.42507	46	9.44102	49	0.55898	9.98405	3	34
27	9.42553	46	9.44151	50	0.55849	9.98402	4	33
28	9.42599	45	9.44201	49	0.55799	9.98398	3	32
29	9.42644	46	9.44250	49	0.55750	9.98395	4	31
30	9.42690	45	9.44299	49	0.55701	9.98391	3	30
31	9.42735	46	9.44348	49	0.55652	9.98388	4	29
32	9.42781	45	9.44397	49	0.55603	9.98384	3	28
33	9.42826	46	9.44446	49	0.55554	9.98381	4	27
34	9.42872	45	9.44495	49	0.55505	9.98377	4	26
35	9.42917	45	9.44544	48	0.55456	9.98373	3	25
36	9.42962	46	9.44592	49	0.55408	9.98370	4	24
37	9.43008	45	9.44641	49	0.55359	9.98366	3	23
38	9.43053	45	9.44690	48	0.55310	9.98363	4	22
39	9.43098	45	9.44738	49	0.55262	9.98359	3	21
40	9.43143	45	9.44787	49	0.55213	9.98356	4	20
41	9.43188	45	9.44836	48	0.55164	9.98352	3	19
42	9.43233	45	9.44884	49	0.55116	9.98349	4	18
43	9.43278	45	9.44933	48	0.55067	9.98345	3	17
44	9.43323	44	9.44981	48	0.55019	9.98342	4	16
45	9.43367	45	9.45029	49	0.54971	9.98338	4	15
46	9.43412	45	9.45078	48	0.54922	9.98334	3	14
47	9.43457	45	9.45126	48	0.54874	9.98331	4	13
48	9.43502	44	9.45174	48	0.54826	9.98327	3	12
49	9.43546	45	9.45222	49	0.54778	9.98324	4	11
50	9.43591	44	9.45271	48	0.54729	9.98320	3	10
51	9.43635	45	9.45319	48	0.54681	9.98317	4	9
52	9.43680	44	9.45367	48	0.54633	9.98313	4	8
53	9.43724	45	9.45415	48	0.54585	9.98309	3	7
54	9.43769	44	9.45463	48	0.54537	9.98306	4	6
55	9.43813	44	9.45511	48	0.54489	9.98302	3	5
56	9.43857	44	9.45559	47	0.54441	9.98299	4	4
57	9.43901	45	9.45606	48	0.54394	9.98295	4	3
58	9.43946	44	9.45654	48	0.54346	9.98291	3	2
59	9.43990	44	9.45702	48	0.54298	9.98288	4	1
60	9.44034		9.45750		0.54250	9.98284		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

P. P.

	51	50
6	5.1	5.0
7	6.0	5.8
8	6.8	6.7
9	7.7	7.5
10	8.5	8.3
20	17.0	16.7
30	25.5	25.0
40	34.0	33.3
50	42.5	41.7

	49	48
6	4.9	4.8
7	5.7	5.6
8	6.5	6.4
9	7.4	7.2
10	8.2	8.0
20	16.3	16.0
30	24.5	24.0
40	32.7	32.0
50	40.8	40.0

	47	46
6	4.7	4.6
7	5.5	5.4
8	6.3	6.1
9	7.1	6.9
10	7.8	7.7
20	15.7	15.3
30	23.5	23.0
40	31.3	30.7
50	39.2	38.3

	45	44
6	4.5	4.4
7	5.3	5.1
8	6.0	5.9
9	6.8	6.6
10	7.5	7.3
20	15.0	14.7
30	22.5	22.0
40	30.0	29.3
50	37.5	36.7

	4	3
6	0.4	0.3
7	0.5	0.4
8	0.5	0.4
9	0.6	0.5
10	0.7	0.5
20	1.3	1.0
30	2.0	1.5
40	2.7	2.0
50	3.3	2.5

P. P.

74°

16°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.44034	44	9.45750	47	0.54250	9.98284	3	60
1	9.44078	44	9.45797	48	0.54203	9.98281	4	59
2	9.44122	44	9.45845	47	0.54155	9.98277	4	58
3	9.44166	44	9.45892	48	0.54108	9.98273	3	57
4	9.44210	43	9.45940	47	0.54060	9.98270	4	56
5	9.44253	44	9.45987	48	0.54013	9.98266	4	55
6	9.44297	44	9.46035	47	0.53965	9.98262	3	54
7	9.44341	44	9.46082	48	0.53918	9.98259	4	53
8	9.44385	43	9.46130	47	0.53870	9.98255	4	52
9	9.44428	44	9.46177	47	0.53823	9.98251	3	51
10	9.44472	44	9.46224	47	0.53776	9.98248	4	50
11	9.44516	43	9.46271	48	0.53729	9.98244	4	49
12	9.44559	43	9.46319	47	0.53681	9.98240	3	48
13	9.44602	44	9.46366	47	0.53634	9.98237	4	47
14	9.44646	43	9.46413	47	0.53587	9.98233	4	46
15	9.44689	44	9.46460	47	0.53540	9.98229	3	45
16	9.44733	43	9.46507	47	0.53493	9.98226	4	44
17	9.44776	43	9.46554	47	0.53446	9.98222	4	43
18	9.44819	43	9.46601	47	0.53399	9.98218	3	42
19	9.44862	43	9.46648	46	0.53352	9.98215	4	41
20	9.44905	43	9.46694	47	0.53306	9.98211	4	40
21	9.44948	44	9.46741	47	0.53259	9.98207	3	39
22	9.44992	43	9.46788	47	0.53212	9.98204	4	38
23	9.45035	42	9.46835	46	0.53165	9.98200	4	37
24	9.45077	43	9.46881	47	0.53119	9.98196	4	36
25	9.45120	43	9.46928	47	0.53072	9.98192	3	35
26	9.45163	43	9.46975	46	0.53025	9.98189	4	34
27	9.45206	43	9.47021	47	0.52979	9.98185	4	33
28	9.45249	43	9.47068	46	0.52932	9.98181	4	32
29	9.45292	42	9.47114	46	0.52886	9.98177	3	31
30	9.45334	43	9.47160	47	0.52840	9.98174	4	30
31	9.45377	42	9.47207	46	0.52793	9.98170	4	29
32	9.45419	43	9.47253	46	0.52747	9.98166	4	28
33	9.45462	42	9.47299	47	0.52701	9.98162	3	27
34	9.45504	43	9.47346	46	0.52654	9.98159	4	26
35	9.45547	42	9.47392	46	0.52608	9.98155	4	25
36	9.45589	43	9.47438	46	0.52562	9.98151	4	24
37	9.45632	42	9.47484	46	0.52516	9.98147	3	23
38	9.45674	42	9.47530	46	0.52470	9.98144	4	22
39	9.45716	42	9.47576	46	0.52424	9.98140	4	21
40	9.45758	43	9.47622	46	0.52378	9.98136	4	20
41	9.45801	42	9.47668	46	0.52332	9.98132	3	19
42	9.45843	42	9.47714	46	0.52286	9.98129	4	18
43	9.45885	42	9.47760	46	0.52240	9.98125	4	17
44	9.45927	42	9.47806	46	0.52194	9.98121	4	16
45	9.45969	42	9.47852	45	0.52148	9.98117	4	15
46	9.46011	42	9.47897	46	0.52103	9.98113	3	14
47	9.46053	42	9.47943	46	0.52057	9.98110	4	13
48	9.46095	41	9.47989	46	0.52011	9.98106	4	12
49	9.46136	42	9.48035	45	0.51965	9.98102	4	11
50	9.46178	42	9.48080	46	0.51920	9.98098	4	10
51	9.46220	42	9.48126	45	0.51874	9.98094	4	9
52	9.46262	41	9.48171	46	0.51829	9.98090	3	8
53	9.46303	42	9.48217	45	0.51783	9.98087	4	7
54	9.46345	41	9.48262	45	0.51738	9.98083	4	6
55	9.46386	42	9.48307	46	0.51693	9.98079	4	5
56	9.46428	41	8.48353	45	0.51647	9.98075	4	4
57	9.46469	42	9.48398	45	0.51602	9.98071	4	3
58	9.46511	41	9.48443	46	0.51557	9.98067	4	2
59	9.46552	42	9.48489	45	0.51511	9.98063	3	1
60	9.46594		9.48534		0.51466	9.98060		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

P. P.

	48	47
6	4.8	4.7
7	5.6	5.5
8	6.4	6.3
9	7.2	7.1
10	8.0	7.8
20	16.0	15.7
30	24.0	23.5
40	32.0	31.3
50	40.0	39.2

	46	45
6	4.6	4.5
7	5.4	5.3
8	6.1	6.0
9	6.9	6.8
10	7.7	7.5
20	15.3	15.0
30	23.0	22.5
40	30.7	30.0
50	38.3	37.5

	44	43
6	4.4	4.3
7	5.1	5.0
8	5.9	5.7
9	6.6	6.5
10	7.3	7.2
20	14.7	14.3
30	22.0	21.5
40	29.3	28.7
50	36.7	35.8

	42	41
6	4.2	4.1
7	4.9	4.8
8	5.6	5.5
9	6.3	6.2
10	7.0	6.8
20	14.0	13.7
30	21.0	20.5
40	28.0	27.3
50	35.0	34.2

	4	3
6	0.4	0.3
7	0.5	0.4
8	0.5	0.4
9	0.6	0.5
10	0.7	0.5
20	1.3	1.0
30	2.0	1.5
40	2.7	2.0
50	3.3	2.5

P. P.

73°

17°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.46594	41	9.48534	45	0.51466	9.98060	4	60
1	9.46635	41	9.48579	45	0.51421	9.98056	4	59
2	9.46676	41	9.48624	45	0.51376	9.98052	4	58
3	9.46717	41	9.48669	45	0.51331	9.98048	4	57
4	9.46758	42	9.48714	45	0.51286	9.98044	4	56
5	9.46800	41	9.48759	45	0.51241	9.98040	4	55
6	9.46841	41	9.48804	45	0.51196	9.98036	4	54
7	9.46882	41	9.48849	45	0.51151	9.98032	3	53
8	9.46923	41	9.48894	45	0.51106	9.98029	4	52
9	9.46964	41	9.48939	45	0.51061	9.98025	4	51
10	9.47005	40	9.48984	45	0.51016	9.98021	4	50
11	9.47045	41	9.49029	44	0.50971	9.98017	4	49
12	9.47086	41	9.49073	45	0.50927	9.98013	4	48
13	9.47127	41	9.49118	45	0.50882	9.98009	4	47
14	9.47168	41	9.49163	44	0.50837	9.98005	4	46
15	9.47209	40	9.49207	45	0.50793	9.98001	4	45
16	9.47249	41	9.49252	44	0.50748	9.97997	4	44
17	9.47290	40	9.49296	45	0.50704	9.97993	4	43
18	9.47330	41	9.49341	44	0.50659	9.97989	3	42
19	9.47371	40	9.49385	45	0.50615	9.97986	4	41
20	9.47411	41	9.49430	44	0.50570	9.97982	4	40
21	9.47452	40	9.49474	45	0.50526	9.97978	4	39
22	9.47492	41	9.49519	44	0.50481	9.97974	4	38
23	9.47533	40	9.49563	44	0.50437	9.97970	4	37
24	9.47573	40	9.49607	45	0.50393	9.97966	4	36
25	9.47613	41	9.49652	44	0.50348	9.97962	4	35
26	9.47654	40	9.49696	44	0.50304	9.97958	4	34
27	9.47694	40	9.49740	44	0.50260	9.97954	4	33
28	9.47734	40	9.49784	44	0.50216	9.97950	4	32
29	9.47774	40	9.49828	44	0.50172	9.97946	4	31
30	9.47814	40	9.49872	44	0.50128	9.97942	4	30
31	9.47854	40	9.49916	44	0.50084	9.97938	4	29
32	9.47894	40	9.49960	44	0.50040	9.97934	4	28
33	9.47934	40	9.50004	44	0.49996	9.97930	4	27
34	9.47974	40	9.50048	44	0.49952	9.97926	4	26
35	9.48014	40	9.50092	44	0.49908	9.97922	4	25
36	9.48054	40	9.50136	44	0.49864	9.97918	4	24
37	9.48094	39	9.50180	43	0.49820	9.97914	4	23
38	9.48133	40	9.50223	44	0.49777	9.97910	4	22
39	9.48173	40	9.50267	44	0.49733	9.97906	4	21
40	9.48213	39	9.50311	44	0.49689	9.97902	4	20
41	9.48252	40	9.50355	43	0.49645	9.97898	4	19
42	9.48292	40	9.50398	44	0.49602	9.97894	4	18
43	9.48332	39	9.50442	43	0.49558	9.97890	4	17
44	9.48371	40	9.50485	44	0.49515	9.97886	4	16
45	9.48411	39	9.50529	43	0.49471	9.97882	4	15
46	9.48450	40	9.50572	44	0.49428	9.97878	4	14
47	9.48490	39	9.50616	43	0.49384	9.97874	4	13
48	9.48529	39	9.50659	44	0.49341	9.97870	4	12
49	9.48568	39	9.50703	43	0.49297	9.97866	5	11
50	9.48607	40	9.50746	43	0.49254	9.97861	4	10
51	9.48647	39	9.50789	44	0.49211	9.97857	4	9
52	9.48686	39	9.50833	43	0.49167	9.97853	4	8
53	9.48725	39	9.50876	43	0.49124	9.97849	4	7
54	9.48764	39	9.50919	43	0.49081	9.97845	4	6
55	9.48803	39	9.50962	43	0.49038	9.97841	4	5
56	9.48842	39	9.51005	43	0.48995	9.97837	4	4
57	9.48881	39	9.51048	44	0.48952	9.97833	4	3
58	9.48920	39	9.51092	43	0.48908	9.97829	4	2
59	9.48959	39	9.51135	43	0.48865	9.97825	4	1
60	9.48998		9.51178		0.48822	9.97821		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

P. P.

	45	44
6	4.5	4.4
7	5.3	5.1
8	6.0	5.9
9	6.8	6.6
10	7.5	7.3
20	15.0	14.7
30	22.5	22.0
40	30.0	29.3
50	37.5	36.7

	43
6	4.3
7	5.0
8	5.7
9	6.5
10	7.2
20	14.3
30	21.5
40	28.7
50	35.8

	42	41
6	4.2	4.1
7	4.9	4.8
8	5.6	5.5
9	6.3	6.2
10	7.0	6.8
20	14.0	13.7
30	21.0	20.5
40	28.0	27.3
50	35.0	34.2

	40	39
6	4.0	3.9
7	4.7	4.6
8	5.3	5.2
9	6.0	5.9
10	6.7	6.5
20	13.3	13.0
30	20.0	19.5
40	26.7	26.0
50	33.3	32.5

	5	4	3
6	0.5	0.4	0.3
7	0.6	0.5	0.4
8	0.7	0.5	0.4
9	0.8	0.6	0.5
10	0.8	0.7	0.5
20	1.7	1.3	1.0
30	2.5	2.0	1.5
40	3.3	2.7	2.0
50	4.2	3.3	2.5

P. P.

72°

18°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.48998	39	9.51178	43	0.48822	9.97821	4	60
1	9.49037	39	9.51221	43	0.48779	9.97817	5	59
2	9.49076	39	9.51264	42	0.48736	9.97812	4	58
3	9.49115	38	9.51306	43	0.48694	9.97808	4	57
4	9.49153	39	9.51349	43	0.48651	9.97804	4	56
5	9.49192	39	9.51392	43	0.48608	9.97800	4	55
6	9.49231	38	9.51435	43	0.48565	9.97796	4	54
7	9.49269	39	9.51478	42	0.48522	9.97792	4	53
8	9.49308	39	9.51520	43	0.48480	9.97788	4	52
9	9.49347	38	9.51563	43	0.48437	9.97784	5	51
10	9.49385	39	9.51606	42	0.48394	9.97779	4	50
11	9.49424	38	9.51648	43	0.48352	9.97775	4	49
12	9.49462	38	9.51691	43	0.48309	9.97771	4	48
13	9.49500	39	9.51734	42	0.48266	9.97767	4	47
14	9.49539	38	9.51776	43	0.48224	9.97763	4	46
15	9.49577	38	9.51819	42	0.48181	9.97759	5	45
16	9.49615	39	9.51861	42	0.48139	9.97754	4	44
17	9.49654	38	9.51903	43	0.48097	9.97750	4	43
18	9.49692	38	9.51946	42	0.48054	9.97746	4	42
19	9.49730	38	9.51988	43	0.48012	9.97742	4	41
20	9.49768	38	9.52031	42	0.47969	9.97738	4	40
21	9.49806	38	9.52073	42	0.47927	9.97734	5	39
22	9.49844	38	9.52115	42	0.47885	9.97729	4	38
23	9.49882	38	9.52157	43	0.47843	9.97725	4	37
24	9.49920	38	9.52200	42	0.47800	9.97721	4	36
25	9.49958	38	9.52242	42	0.47758	9.97717	4	35
26	9.49996	38	9.52284	42	0.47716	9.97713	5	34
27	9.50034	38	9.52326	42	0.47674	9.97708	4	33
28	9.50072	38	9.52368	42	0.47632	9.97704	4	32
29	9.50110	38	9.52410	42	0 47590	9.97700	4	31
30	9.50148	37	9.52452	42	0.47548	9.97696	5	30
31	9.50185	38	9.52494	42	0.47506	9.97691	4	29
32	9.50223	38	9.52536	42	0.47464	9.97687	4	28
33	9.50261	37	9.52578	42	0.47422	9.97683	4	27
34	9.50298	38	9.52620	41	0.47380	9.97679	5	26
35	9.50336	38	9.52661	42	0.47339	9.97674	4	25
36	9.50374	37	9.52703	42	0.47297	9.97670	4	24
37	9.50411	38	9.52745	42	0.47255	9.97666	4	23
38	9.50449	37	9.52787	42	0.47213	9.97662	5	22
39	9.50486	37	9.52829	41	0.47171	9.97657	4	21
40	9.50523	38	9.52870	42	0.47130	9.97653	4	20
41	9.50561	37	9.52912	41	0.47088	9.97649	4	19
42	9.50598	37	9.52953	42	0.47047	9.97645	5	18
43	9.50635	38	9.52995	42	0.47005	9.97640	4	17
44	9.50673	37	9.53037	41	0.46963	9 97636	4	16
45	9.50710	37	9.53078	42	0.46922	9.97632	4	15
46	9.50747	37	9.53120	41	0.46880	9.97628	5	14
47	9.50784	37	9.53161	41	0.46839	9.97623	4	13
48	9.50821	37	9.53202	42	0.46798	9.97619	4	12
49	9.50858	38	9.53244	41	0.46756	9.97615	5	11
50	9.50896	37	9.53285	42	0.46715	9.97610	4	10
51	9.50933	37	9.53327	41	0.46673	9.97606	4	9
52	9.50970	37	9.53368	41	0.46632	9.97602	5	8
53	9.51067	36	9.53409	41	0.46591	9.97597	4	7
54	9.51043	37	9.53450	42	0.46550	9.97593	4	6
55	9.51080	37	9.53492	41	0.46508	9.97589	5	5
56	9.51117	37	9.53533	41	0.46467	9.97584	4	4
57	9.51154	37	9.53574	41	0.46426	9.97580	4	3
58	9.51191	36	9.53615	41	0.46385	9.97576	5	2
59	9.51227	37	9.53656	41	0.46344	9.97571	4	1
60	9.51264		9.53697		0.46303	9.97567		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

P. P.

	43	42
6	4.3	4.2
7	5.0	4.9
8	5.7	5.6
9	6.5	6.3
10	7.2	7.0
20	14.3	14.0
30	21.5	21.0
40	28.7	28.0
50	35.8	35.0

	41
6	4.1
7	4.8
8	5.5
9	6.2
10	6.8
20	13.7
30	20.5
40	27.3
50	34.2

	39	38
6	3.9	3.8
7	4.6	4.4
8	5.2	5.1
9	5.9	5.7
10	6.5	6.3
20	13.0	12.7
30	19.5	19.0
40	26.0	25.3
50	32.5	31.7

	37	36
6	3.7	3.6
7	4.3	4.2
8	4.9	4.8
9	5.6	5.4
10	6.2	6.0
20	12.3	12.0
30	18.5	18.0
40	24.7	24.0
50	30.8	30.0

	5	4
6	0.5	0.4
7	0.6	0.5
8	0.7	0.5
9	0.8	0.6
10	0.8	0.7
20	1.7	1.3
30	2.5	2.0
40	3.3	2.7
50	4.2	3.3

P. P.

71°

19°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.51264	37	9.53697	41	0.46303	9.97567	4	60
1	9.51301	37	9.53738	41	0.46262	9.97563	5	59
2	9.51338	36	9.53779	41	0.46221	9.97558	4	58
3	9.51374	37	9.53820	41	0.46180	9.97554	4	57
4	9.51411	36	9.53861	41	0.46139	9.97550	5	56
5	9.51447	37	9.53902	41	0.46098	9.97545	4	55
6	9.51484	36	9.53943	41	0.46057	9.97541	5	54
7	9.51520	37	9.53984	41	0.46016	9.97536	4	53
8	9.51557	36	9.54025	40	0.45975	9.97532	4	52
9	9.51593	36	9.54065	41	0.45935	9.97528	5	51
10	9.51629	37	9.54106	41	0.45894	9.97523	4	50
11	9.51666	36	9.54147	40	0.45853	9.97519	4	49
12	9.51702	36	9.54187	41	0.45813	9.97515	5	48
13	9.51738	36	9.54228	41	0.45772	9 97510	4	47
14	9.51774	37	9.54269	40	0.45731	9.97506	5	46
15	9.51811	36	9.54309	41	0.45691	9.97501	4	45
16	9.51847	36	9.54350	40	0.45650	9.97497	5	44
17	9.51883	36	9.54390	41	0.45610	9.97492	4	43
18	9.51919	36	9.54431	40	0.45569	9.97488	4	42
19	9.51955	36	9.54471	41	0.45529	9.97484	5	41
20	9.51991	36	9.54512	40	0.45488	9.97479	4	40
21	9.52027	36	9.54552	41	0.45448	9.97475	5	39
22	9.52063	36	9.54593	40	0.45407	9.97470	4	38
23	9.52099	36	9.54633	40	0.45367	9.97466	5	37
24	9.52135	36	9.54673	41	0.45327	9.97461	4	36
25	9.52171	36	9.54714	40	0.45286	9.97457	4	35
26	9.52207	35	9.54754	40	0.45246	9.97453	5	34
27	9.52242	36	9.54794	41	0.45206	9.97448	4	33
28	9.52278	36	9.54835	40	0.45165	9.97444	5	32
29	9.52314	36	9.54875	40	0.45125	9.97439	4	31
30	9.52350	35	9.54915	40	0.45085	9.97435	5	30
31	9.52385	36	9.54955	40	0.45045	9.97430	4	29
32	9.52421	35	9.54995	40	0.45005	9.97426	5	28
33	9.52456	36	9.55035	40	0.44965	9.97421	4	27
34	9.52492	35	9.55075	40	0.44925	9.97417	5	26
35	9.52527	36	9.55115	40	0.44885	9.97412	4	25
36	9.52563	35	9.55155	40	0.44845	9.97408	5	24
37	9.52598	36	9.55195	40	0.44805	9.97403	4	23
38	9.52634	35	9 55235	40	0.44765	9.97399	5	22
39	9.52669	36	9.55275	40	0.44725	9.97394	4	21
40	9.52705	35	9.55315	40	0.44685	9.97390	5	20
41	9.52740	35	9.55355	40	0.44645	9.97385	4	19
42	9.52775	36	9.55395	39	0.44605	9.97381	5	18
43	9.52811	35	9.55434	40	0.44566	9.97376	4	17
44	9.52846	35	9.55474	40	0.44526	9.97372	5	16
45	9.52881	35	9.55514	40	0.44486	9.97367	4	15
46	9.52916	35	9.55554	39	0.44446	9.97363	5	14
47	9.52951	35	9.55593	40	0.44407	9.97358	5	13
48	9.52986	35	9.55633	40	0.44367	9.97353	4	12
49	9.53021	35	9.55673	39	0.44327	9.97349	5	11
50	9.53056	36	9.55712	40	0.44288	9.97344	4	10
51	9.53092	34	9.55752	39	0.44248	9.97340	5	9
52	9.53126	35	9.55791	40	0.44209	9.97335	4	8
53	9.53161	35	9.55831	39	0.44169	9.97331	5	7
54	9.53196	35	9.55870	40	0.44130	9.97326	4	6
55	9.53231	35	9.55910	39	0.44090	9.97322	5	5
56	9.53266	35	9.55949	40	0.44051	9.97317	5	4
57	9.53301	35	9.55989	39	0.44011	9.97312	4	3
58	9.53336	34	9.56028	39	0.43972	9.97308	5	2
59	9.53370	35	9.56067	40	0.43933	9.97303	4	1
60	9.53405		9.56107		0.43893	9.97299		0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	d.	′

P. P.

	41	40
6	4.1	4.0
7	4.8	4.7
8	5.5	5.3
9	6.2	6.0
10	6.8	6.7
20	13.7	13.3
30	20.5	20.0
40	27.3	26.7
50	34.2	33.3

	39
6	3.9
7	4.6
8	5.2
9	5.9
10	6.5
20	13.0
30	19.5
40	26.0
50	32.5

	37	36
6	3.7	3.6
7	4.3	4.2
8	4.9	4.8
9	5.6	5.4
10	6.2	6.0
20	12.3	12.0
30	18.5	18.0
40	24.7	24.0
50	30.8	30.0

	35	34
6	3.5	3.4
7	4.1	4.0
8	4.7	4.5
9	5.3	5.1
10	5.8	5.7
20	11.7	11.3
30	17.5	17.0
40	23.3	22.7
50	29.2	28.3

	5	4
6	0.5	0.4
7	0.6	0.5
8	0.7	0.5
9	0.8	0.6
10	0.8	0.7
20	1.7	1.3
30	2.5	2.0
40	3.3	2.7
50	4.2	3.3

P. P.

70°

20°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.53405	35	9.56107	39	0.43893	9.97299	5	60
1	9.53440	35	9.56146	39	0.43854	9.97294	5	59
2	9.53475	34	9.56185	39	0.43815	9.97289	4	58
3	9.53509	35	9.56224	40	0.43776	9.97285	5	57
4	9.53544	34	9.56264	39	0.43736	9.97280	4	56
5	9.53578	35	9.56303	39	0.43697	9.97276	5	55
6	9.53613	34	9.56342	39	0.43658	9.97271	5	54
7	9.53647	35	9.56381	39	0.43619	9.97266	4	53
8	9.53682	34	9.56420	39	0.43580	9.97262	5	52
9	9.53716	35	9.56459	39	0.43541	9.97257	5	51
10	9.53751	34	9.56498	39	0.43502	9.97252	4	50
11	9.53785	34	9.56537	39	0.43463	9.97248	5	49
12	9.53819	35	9.56576	39	0.43424	9.97243	5	48
13	9.53854	34	9.56615	39	0.43385	9.97238	4	47
14	9.53888	34	9.56654	39	0.43346	9.97234	5	46
15	9.53922	35	9.56693	39	0.43307	9.97229	5	45
16	9.53957	34	9.56732	39	0.43268	9.97224	4	44
17	9.53991	34	9.56771	39	0.43229	9.97220	5	43
18	9.54025	34	9.56810	39	0.43190	9.97215	5	42
19	9.54059	34	9.56849	38	0.43151	9.97210	4	41
20	9.54093	34	9.56887	39	0.43113	9.97206	5	40
21	9 54127	34	9.56926	39	0.43074	9.97201	5	39
22	9.54161	34	9.56965	39	0.43035	9.97196	4	38
23	9.54195	34	9.57004	38	0.42996	9.97192	5	37
24	9.54229	34	9.57042	39	0.42958	9.97187	5	36
25	9.54263	34	9.57081	39	0.42919	9.97182	4	35
26	9.54297	34	9.57120	38	0.42880	9.97178	5	34
27	9.54331	34	9.57158	39	0.42842	9.97173	5	33
28	9.54365	34	9.57197	38	0.42803	9.97168	5	32
29	9.54399	34	9.57235	39	0.42765	9.97163	4	31
30	9.54433	33	9.57274	38	0.42726	9.97159	5	30
31	9.54466	34	9.57312	39	0.42688	9.97154	5	29
32	9.54500	34	9.57351	38	0.42649	9.97149	4	28
33	9.54534	33	9.57389	39	0.42611	9.97145	5	27
34	9.54567	34	9.57428	38	0.42572	9.97140	5	26
35	9.54601	34	9.57466	38	0.42534	9.97135	5	25
36	9.54635	33	9.57504	39	0.42496	9.97130	4	24
37	9.54668	34	9.57543	38	0.42457	9.97126	5	23
38	9.54702	33	9.57581	38	0.42419	9.97121	5	22
39	9.54735	34	9.57619	39	0.42381	9.97116	5	21
40	9.54769	33	9.57658	38	0.42342	9.97111	4	20
41	9.54802	34	9.57696	38	0.42304	9.97107	5	19
42	9.54836	33	9.57734	38	0.42266	9.97102	5	18
43	9.54869	34	9.57772	38	0.42228	9.97097	5	17
44	9.54903	33	9.57810	39	0.42190	9.97092	5	16
45	9.54936	33	9.57849	38	0.42151	9.97087	4	15
46	9.54969	34	9.57887	38	0.42113	9.97083	5	14
47	9.55003	33	9.57925	38	0.42075	9.97078	5	13
48	9.55036	33	9.57963	38	0.42037	9.97073	5	12
49	9.55069	33	9.58001	38	0.41999	9.97068	5	11
50	9.55102	34	9.58039	38	0.41961	9.97063	4	10
51	9.55136	33	9.58077	38	0.41923	9.97059	5	9
52	9.55169	33	9.58115	38	0.41885	9.97054	5	8
53	9.55202	33	9.58153	38	0.41847	9.97049	5	7
54	9.55235	33	9.58191	38	0.41809	9.97044	5	6
55	9.55268	33	9.58229	38	0.41771	9.97039	4	5
56	9.55301	33	9.58267	37	0.41733	9.97035	5	4
57	9.55334	33	9.58304	38	0.41696	9.97030	5	3
58	9.55367	33	9.58342	38	0.41658	9.97025	5	2
59	9.55400	33	9.58380	38	0.41620	9.97020	5	1
60	9.55433		9.58418		0.41582	9.97015		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

P. P.

	40	39
6	4.0	3.9
7	4.7	4.6
8	5.3	5.2
9	6.0	5.9
10	6.7	6.5
20	13.3	13.0
30	20.0	19.5
40	26.7	26.0
50	33.3	32.5

	38	37
6	3.8	3.7
7	4.4	4.3
8	5.1	4.9
9	5.7	5.6
10	6.3	6.2
20	12.7	12.3
30	19.0	18.5
40	25.3	24.7
50	31.7	30.8

	35
6	3.5
7	4.1
8	4.7
9	5.3
10	5.8
20	11.7
30	17.5
40	23.3
50	29.2

	34	33
6	3.4	3.3
7	4.0	3.9
8	4.5	4.4
9	5.1	5.0
10	5.7	5.5
20	11.3	11.0
30	17.0	16.5
40	22.7	22.0
50	28.3	27.5

	5	4
6	0.5	0.4
7	0.6	0.5
8	0.7	0.5
9	0.8	0.6
10	0.8	0.7
20	1.7	1.3
30	2.5	2.0
40	3.3	2.7
50	4.2	3.3

P. P.

69°

21°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.55433	33	9.58418	37	0.41582	9.97015	5	60
1	9.55466	33	9.58455	38	0.41545	9.97010	5	59
2	9.55499	33	9.58493	38	0.41507	9.97005	4	58
3	9.55532	32	9.58531	38	0.41469	9.97001	5	57
4	9.55564	33	9.58569	37	0.41431	9.96996	5	56
5	9.55597	33	9.58606	38	0.41394	9.96991	5	55
6	9.55630	33	9.58644	37	0.41356	9.96986	5	54
7	9.55663	32	9.58681	38	0.41319	9.96981	5	53
8	9.55695	33	9.58719	38	0.41281	9.96976	5	52
9	9.55728	33	9.58757	37	0.41243	9.96971	5	51
10	9.55761	32	9.58794	38	0.41206	9.96966	4	50
11	9.55793	33	9.58832	37	0.41168	9.96962	5	49
12	9.55826	32	9.58869	38	0.41131	9.96957	5	48
13	9.55858	33	9.58907	37	0.41093	9.96952	5	47
14	9.55891	32	9.58944	37	0.41056	9.96947	5	46
15	9.55923	33	9.58981	38	0.41019	9.96942	5	45
16	9.55956	32	9.59019	37	0.40981	9.96937	5	44
17	9.55988	33	9.59056	38	0.40944	9.96932	5	43
18	9.56021	32	9.59094	37	0.40906	9.96927	5	42
19	9.56053	32	9.59131	37	0.40869	9.96922	5	41
20	9.56085	33	9.59168	37	0.40832	9.96917	5	40
21	9.56118	32	9.59205	38	0.40795	9.96912	5	39
22	9.56150	32	9.59243	37	0.40757	9.96907	4	38
23	9.56182	33	9.59280	37	0.40720	9.96903	5	37
24	9.56215	32	9.59317	37	0.40683	9.96898	5	36
25	9.56247	32	9.59354	37	0.40646	9.96893	5	35
26	9.56279	32	9.59391	38	0.40609	9.96888	5	34
27	9.56311	32	9.59429	37	0.40571	9.96883	5	33
28	9.56343	32	9.59466	37	0.40534	9.96878	5	32
29	9.56375	33	9.59503	37	0.40497	9.96873	5	31
30	9.56408	32	9.59540	37	0.40460	9.96868	5	30
31	9.56440	32	9.59577	37	0.40423	9.96863	5	29
32	9.56472	32	9.59614	37	0.40386	9.96858	5	28
33	9.56504	32	9.59651	37	0.40349	9.96853	5	27
34	9.56536	32	9.59688	37	0.40312	9.96848	5	26
35	9.56568	31	9.59725	37	0.40275	9.96843	5	25
36	9.56599	32	9.59762	37	0.40238	9.96838	5	24
37	9.56631	32	9.59799	36	0.40201	9.96833	5	23
38	9.56663	32	9.59835	37	0.40165	9.96828	5	22
39	9.56695	32	9.59872	37	0.40128	9.96823	5	21
40	9.56727	32	9.59909	37	0.40091	9.96818	5	20
41	9.56759	31	9.59946	37	0.40054	9.96813	5	19
42	9.56790	32	9.59983	36	0.40017	9.96808	5	18
43	9.56822	32	9.60019	37	0.39981	9.96803	5	17
44	9.56854	32	9.60056	37	0.39944	9.96798	5	16
45	9.56886	31	9.60093	37	0.39907	9.96793	5	15
46	9.56917	32	9.60130	36	0.39870	9.96788	5	14
47	9.56949	31	9.60166	37	0.39834	9.96783	5	13
48	9.56980	32	9.60203	37	0.39797	9.96778	6	12
49	9.57012	32	9.60240	36	0.39760	9.96772	5	11
50	9.57044	31	9.60276	37	0.39724	9.96767	5	10
51	9.57075	32	9.60313	36	0.39687	9.96762	5	9
52	9.57107	31	9.60349	37	0.39651	9.96757	5	8
53	9.57138	31	9.60386	36	0.39614	9.96752	5	7
54	9.57169	32	9.60422	37	0.39578	9.96747	5	6
55	9.57201	31	9.60459	36	0.39541	9.96742	5	5
56	9.57232	32	9.60495	37	0.39505	9.96737	5	4
57	9.57264	31	9.60532	36	0.39468	9.96732	5	3
58	9.57295	31	9.60568	37	0.39432	9.96727	5	2
59	9.57326	32	9.60605	36	0.39395	9.96722	5	1
60	9.57358		9.60641		0.39359	9.96717		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

68°

P. P.

	38	37	36	33	32	31	6	5	4
6	3.8	3.7	3.6	3.3	3.2	3.1	0.6	0.5	0.4
7	4.4	4.3	4.2	3.9	3.7	3.6	0.7	0.6	0.5
8	5.1	4.9	4.8	4.4	4.3	4.1	0.8	0.7	0.5
9	5.7	5.6	5.4	5.0	4.8	4.7	0.9	0.8	0.6
10	6.3	6.2	6.0	5.5	5.3	5.2	1.0	0.8	0.7
20	12.7	12.3	12.0	11.0	10.7	10.3	2.0	1.7	1.3
30	19.0	18.5	18.0	16.5	16.0	15.5	3.0	2.5	2.0
40	25.3	24.7	24.0	22.0	21.3	20.7	4.0	3.3	2.7
50	31.7	30.8	30.0	27.5	26.7	25.8	5.0	4.2	3.3

P. P.

22°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.57358		9.60641		0.39359	9.96717		**60**
1	9.57389	31	9.60677	36	0.39323	9.96711	6	59
2	9.57420	31	9.60714	37	0.39286	9.96706	5	58
3	9.57451	31	9.60750	36	0.39250	9.96701	5	57
4	9.57482	31	9.60786	36	0.39214	9.96696	5	56
5	9.57514	32	9.60823	37	0.39177	9.96691	5	55
6	9.57545	31	9.60859	36	0.39141	9.96686	5	54
7	9.57576	31	9.60895	36	0.39105	9.96681	5	53
8	9.57607	31	9.60931	36	0.39069	9.96676	5	52
9	9.57638	31	9.60967	36	0.39033	9.96670	6	51
10	9.57669	31	9.61004	37	0.38996	9.96665	5	**50**
11	9.57700	31	9.61040	36	0.38960	9.96660	5	49
12	9.57731	31	9.61076	36	0.38924	9.96655	5	48
13	9.57762	31	9.61112	36	0.38888	9.96650	5	47
14	9.57793	31	9.61148	36	0.38852	9.96645	5	46
15	9.57824	31	9.61184	36	0.38816	9.96640	5	45
16	9.57855	31	9.61220	36	0.38780	9.96634	6	44
17	9.57885	30	9.61256	36	0.38744	9.96629	5	43
18	9.57916	31	9.61292	36	0.38708	9.96624	5	42
19	9.57947	31	9.61328	36	0.38672	9.96619	5	41
20	9.57978	31	9.61364	36	0.38636	9.96614	5	**40**
21	9.58008	30	9.61400	36	0.38600	9.96608	6	39
22	9.58039	31	9.61436	36	0.38564	9.96603	5	38
23	9.58070	31	9.61472	36	0.38528	9.96598	5	37
24	9.58101	31	9.61508	36	0.38492	9.96593	5	36
25	9.58131	30	9.61544	36	0.38456	9.96588	5	35
26	9.58162	31	9.61579	35	0.38421	9.96582	6	34
27	9.58192	30	9.61615	36	0.38385	9.96577	5	33
28	9.58223	31	9.61651	36	0.38349	9.96572	5	32
29	9.58253	30	9.61687	36	0.38313	9.96567	5	31
30	9.58284	31	9.61722	35	0.38278	9.96562	5	**30**
31	9.58314	30	9.61758	36	0.38242	9.96556	6	29
32	9.58345	31	9.61794	36	0.38206	9.96551	5	28
33	9.58375	30	9.61830	36	0.38170	9.96546	5	27
34	9.58406	31	9.61865	35	0.38135	9.96541	5	26
35	9.58436	30	9.61901	36	0.38099	9.96535	6	25
36	9.58467	31	9.61936	35	0.38064	9.96530	5	24
37	9.58497	30	9.61972	36	0.38028	9.96525	5	23
38	9.58527	30	9.62008	36	0.37992	9.96520	5	22
39	9.58557	30	9.62043	35	0.37957	9.96514	6	21
40	9.58588	31	9.62079	36	0.37921	9.96509	5	**20**
41	9.58618	30	9.62114	35	0.37886	9.96504	5	19
42	9.58648	30	9.62150	36	0.37850	9.96498	6	18
43	9.58678	30	9.62185	35	0.37815	9.96493	5	17
44	9.58709	31	9.62221	36	0.37779	9.96488	5	16
45	9.58739	30	9.62256	35	0.37744	9.96483	5	15
46	9.58769	30	9.62292	36	0.37708	9.96477	6	14
47	9.58799	30	9.62327	35	0.37673	9.96472	5	13
48	9.58829	30	9.62362	35	0.37638	9.96467	5	12
49	9.58859	30	9.62398	36	0.37602	9.96461	6	11
50	9.58889	30	9.62433	35	0.37567	9.96456	5	**10**
51	9.58919	30	9.62468	35	0.37532	9.96451	5	9
52	9.58949	30	9.62504	36	0.37496	9.96445	6	8
53	9.58979	30	9.62539	35	0.37461	9.96440	5	7
54	9.59009	30	9.62574	35	0.37426	9.96435	5	6
55	9.59039	30	9.62609	35	0.37391	9.96429	6	5
56	9.59069	30	9.62645	36	0.37355	9.96424	5	4
57	9.59098	29	9.62680	35	0.37320	9.96419	5	3
58	9.59128	30	9.62715	35	0.37285	9.96413	6	2
59	9.59158	30	9.62750	35	0.37250	9.96408	5	1
60	9.59188	30	9.62785	35	0.37215	9.96403	5	**0**
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	d.	′

P. P.

	37	36
6	3.7	3.6
7	4.3	4.2
8	4.9	4.8
9	5.6	5.4
10	6.2	6.0
20	12.3	12.0
30	18.5	18.0
40	24.7	24.0
50	30.8	30.0

	35
6	3.5
7	4.1
8	4.7
9	5.3
10	5.8
20	11.7
30	17.5
40	23.3
50	29.2

	32	31
6	3.2	3.1
7	3.7	3.6
8	4.3	4.1
9	4.8	4.7
10	5.3	5.2
20	10.7	10.3
30	16.0	15.5
40	21.3	20.7
50	26.7	25.8

	30	29
6	3.0	2.9
7	3.5	3.4
8	4.0	3.9
9	4.5	4.4
10	5.0	4.8
20	10.0	9.7
30	15.0	14.5
40	20.0	19.3
50	25.0	24.2

	6	5
6	0.6	0.5
7	0.7	0.6
8	0.8	0.7
9	0.9	0.8
10	1.0	0.8
20	2.0	1.7
30	3.0	2.5
40	4.0	3.3
50	5.0	4.2

P. P.

67°

23°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.59188	30	9.62785	35	0.37215	9.96403	6	**60**
1	9.59218	29	9.62820	35	0.37180	9.96397	5	59
2	9.59247	30	9.62855	35	0.37145	9.96392	5	58
3	9.59277	30	9.62890	36	0.37110	9.96387	6	57
4	9.59307	29	9.62926	35	0.37074	9.96381	5	56
5	9.59336	30	9.62961	35	0.37039	9.96376	6	55
6	9.59366	30	9.62996	35	0.37004	9.96370	5	54
7	9.59396	29	9.63031	35	0.36969	9.96365	5	53
8	9.59425	30	9.63066	35	0.36934	9.96360	6	52
9	9.59455	29	9.63101	34	0.36899	9.96354	5	51
10	9.59484	30	9.63135	35	0.36865	9.96349	6	**50**
11	9.59514	29	9.63170	35	0.36830	9.96343	5	49
12	9.59543	30	9.63205	35	0.36795	9.96338	5	48
13	9.59573	29	9.63240	35	0.36760	9.96333	6	47
14	9.59602	30	9.63275	35	0.36725	9.96327	5	46
15	9.59632	29	9.63310	35	0.36690	9.96322	6	45
16	9.59661	29	9.63345	34	0.36655	9.96316	5	44
17	9.59690	30	9.63379	35	0.36621	9.96311	6	43
18	9.59720	29	9.63414	35	0.36586	9.96305	5	42
19	9.59749	29	9.63449	35	0.36551	9.96300	6	41
20	9.59778	30	9.63484	35	0.36516	9.96294	5	**40**
21	9.59808	29	9.63519	34	0.36481	9.96289	5	39
22	9.59837	29	9.63553	35	0.36447	9.96284	6	38
23	9.59866	29	9.63588	35	0.36412	9.96278	5	37
24	9.59895	29	9.63623	34	0.36377	9.96273	6	36
25	9.59924	30	9.63657	35	0.36343	9.96267	5	35
26	9.59954	29	9.63692	34	0.36308	9.96262	6	34
27	9.59983	29	9.63726	35	0.36274	9.96256	5	33
28	9.60012	29	9.63761	35	0.36239	9.96251	6	32
29	9.60041	29	9.63796	34	0.36204	9.96245	5	31
30	9.60070	29	9.63830	35	0.36170	9.96240	6	**30**
31	9.60099	29	9.63865	34	0.36135	9.96234	5	29
32	9.60128	29	9.63899	35	0.36101	9.96229	6	28
33	9.60157	29	9.63934	34	0.36066	9.96223	5	27
34	9.60186	29	9.63968	35	0.36032	9.96218	6	26
35	9.60215	29	9.64003	34	0.35997	9.96212	5	25
36	9.60244	29	9.64037	35	0.35963	9.96207	6	24
37	9.60273	29	9.64072	34	0.35928	9.96201	5	23
38	9.60302	29	9.64106	34	0.35894	9.96196	6	22
39	9.60331	28	9.64140	35	0.35860	9.96190	5	21
40	9.60359	29	9.64175	34	0.35825	9.96185	6	**20**
41	9.60388	29	9.64209	34	0.35791	9.96179	5	19
42	9.60417	29	9.64243	35	0.35757	9.96174	6	18
43	9.60446	28	9.64278	34	0.35722	9.96168	6	17
44	9.60474	29	9.64312	34	0.35688	9.96162	5	16
45	9.60503	29	9.64346	35	0.35654	9.96157	6	15
46	9.60532	29	9.64381	34	0.35619	9.96151	5	14
47	9.60561	28	9.64415	34	0.35585	9.96146	6	13
48	9.60589	29	9.64449	34	0.35551	9.96140	5	12
49	9.60618	28	9.64483	34	0.35517	9.96135	6	11
50	9.60646	29	9.64517	35	0.35483	9.96129	6	**10**
51	9.60675	29	9.64552	34	0.35448	9.96123	5	9
52	9.60704	28	9.64586	34	0.35414	9.96118	6	8
53	9.60732	29	9.64620	34	0.35380	9.96112	5	7
54	9.60761	28	9.64654	34	0.35346	9.96107	6	6
55	9.60789	29	9.64688	34	0.35312	9.96101	6	5
56	9.60818	28	9.64722	34	0.35278	9.96095	5	4
57	9.60846	29	9.64756	34	0.35244	9.96090	6	3
58	9.60875	28	9.64790	34	0.35210	9.96084	5	2
59	9.60903	28	9.64824	34	0.35176	9.96079	6	1
60	9.60931		9.64858		0.35142	9.96073		**0**
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	d.	′

P. P.

	36	**35**
6	3.6	3.5
7	4.2	4.1
8	4.8	4.7
9	5.4	5.3
10	6.0	5.8
20	12.0	11.7
30	18.0	17.5
40	24.0	23.3
50	30.0	29.2

	34
6	3.4
7	4.0
8	4.5
9	5.1
10	5.7
20	11.3
30	17.0
40	22.7
50	28.3

	30	**29**
6	3.0	2.9
7	3.5	3.4
8	4.0	3.9
9	4.5	4.4
10	5.0	4.8
20	10.0	9.7
30	15.0	14.5
40	20.0	19.3
50	25.0	24.2

	28
6	2.8
7	3.3
8	3.7
9	4.2
10	4.7
20	9.3
30	14.0
40	18.7
50	23.3

	6	**5**
6	0.6	0.5
7	0.7	0.6
8	0.8	0.7
9	0.9	0.8
10	1.0	0.8
20	2.0	1.7
30	3.0	2.5
40	4.0	3.3
50	5.0	4.2

P. P.

66°

24°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.60931	29	9.64858	34	0.35142	9.96073	6	60
1	9.60960	28	9.64892	34	0.35108	9.96067	5	59
2	9.60988	28	9.64926	34	0.35074	9.96062	6	58
3	9.61016	29	9.64960	34	0.35040	9.96056	6	57
4	9.61045	28	9.64994	34	0.35006	9.96050	5	56
5	9.61073	28	9.65028	34	0.34972	9.96045	6	55
6	9.61101	28	9.65062	34	0.34938	9.96039	5	54
7	9.61129	29	9.65096	34	0.34904	9.96034	6	53
8	9.61158	28	9.65130	34	0.34870	9.96028	6	52
9	9.61186	28	9.65164	33	0.34836	9.96022	5	51
10	9.61214	28	9.65197	34	0.34803	9.96017	6	50
11	9.61242	28	9.65231	34	0.34769	9.96011	6	49
12	9.61270	28	9.65265	34	0.34735	9.96005	5	48
13	9.61298	28	9.65299	34	0.34701	9.96000	6	47
14	9.61326	28	9.65333	33	0.34667	9.95994	6	46
15	9.61354	28	9.65366	34	0.34634	9.95988	6	45
16	9.61382	29	9.65400	34	0.34600	9.95982	5	44
17	9.61411	27	9.65434	33	0.34566	9.95977	6	43
18	9.61438	28	9.65467	34	0.34533	9.95971	6	42
19	9.61466	28	9.65501	34	0.34499	9.95965	5	41
20	9.61494	28	9.65535	33	0.34465	9.95960	6	40
21	9.61522	28	9.65568	34	0.34432	9.95954	6	39
22	9.61550	28	9.65602	34	0.34398	9.95948	6	38
23	9.61578	28	9.65636	33	0.34364	9.95942	5	37
24	9.61606	28	9.65669	34	0.34331	9.95937	6	36
25	9.61634	28	9.65703	33	0.34297	9.95931	6	35
26	9.61662	27	9.65736	34	0.34264	9.95925	5	34
27	9.61689	28	9.65770	33	0.34230	9.95920	6	33
28	9.61717	28	9.65803	34	0.34197	9.95914	6	32
29	9.61745	28	9.65837	33	0.34163	9.95908	6	31
30	9.61773	27	9.65870	34	0.34130	9.95902	5	30
31	9.61800	28	9.65904	33	0.34096	9.95897	6	29
32	9.61828	28	9.65937	34	0.34063	9.95891	6	28
33	9.61856	27	9.65971	33	0.34029	9.95885	6	27
34	9.61883	28	9.66004	34	0.33996	9.95879	6	26
35	9.61911	28	9.66038	33	0.33962	9.95873	5	25
36	9.61939	27	9.66071	33	0.33929	9.95868	6	24
37	9.61966	28	9.66104	34	0.33896	9.95862	6	23
38	9.61994	27	9.66138	33	0.33862	9.95856	6	22
39	9.62021	28	9.66171	33	0.33829	9.95850	6	21
40	9.62049	27	9.66204	34	0.33796	9.95844	5	20
41	9.62076	28	9.66238	33	0.33762	9.95839	6	19
42	9.62104	27	9.66271	33	0.33729	9.95833	6	18
43	9.62131	28	9.66304	33	0.33696	9.95827	6	17
44	9.62159	27	9.66337	34	0.33663	9.95821	6	16
45	9.62186	28	9.66371	33	0.33629	9.95815	5	15
46	9.62214	27	9.66404	33	0.33596	9.95810	6	14
47	9.62241	27	9.66437	33	0.33563	9.95804	6	13
48	9.62268	28	9.66470	33	0.33530	9.95798	6	12
49	9.62296	27	9.66503	34	0.33497	9.95792	6	11
50	9.62323	27	9.66537	33	0.33463	9.95786	6	10
51	9.62350	27	9.66570	33	0.33430	9.95780	5	9
52	9.62377	28	9.66603	33	0.33397	9.95775	6	8
53	9.62405	27	9.66636	33	0.33364	9.95769	6	7
54	9.62432	27	9.66669	33	0.33331	9.95763	6	6
55	9.62459	27	9.66702	33	0.33298	9.95757	6	5
56	9.62486	27	9.66735	33	0.33265	9.95751	6	4
57	9.62513	28	9.66768	33	0.33232	9.95745	6	3
58	9.62541	27	9.66801	33	0.33199	9.95739	6	2
59	9.62568	27	9.66834	33	0.33166	9.95733	5	1
60	9.62595		9.66867		0.33133	9.95728		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

P. P.

	34	33
6	3.4	3.3
7	4.0	3.9
8	4.5	4.4
9	5.1	5.0
10	5.7	5.5
20	11.3	11.0
30	17.0	16.5
40	22.7	22.0
50	28.3	27.5

	29
6	2.9
7	3.4
8	3.9
9	4.4
10	4.8
20	9.7
30	14.5
40	19.3
50	24.2

	28
6	2.8
7	3.3
8	3.7
9	4.2
10	4.7
20	9.3
30	14.0
40	18.7
50	23.3

	27
6	2.7
7	3.2
8	3.6
9	4.1
10	4.5
20	9.0
30	13.5
40	18.0
50	22.5

	6	5
6	0.6	0.5
7	0.7	0.6
8	0.8	0.7
9	0.9	0.8
10	1.0	0.8
20	2.0	1.7
30	3.0	2.5
40	4.0	3.3
50	5.0	4.2

P. P.

65°

25°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.62595	27	9.66867	33	0.33133	9.95728	6	60
1	9.62622	27	9.66900	33	0.33100	9.95722	6	59
2	9.62649	27	9.66933	33	0.33067	9.95716	6	58
3	9.62676	27	9.66966	33	0.33034	9.95710	6	57
4	9.62703	27	9.66999	33	0.33001	9.95704	6	56
5	9.62730	27	9.67032	33	0.32968	9.95698	6	55
6	9.62757	27	9.67065	33	0.32935	9.95692	6	54
7	9.62784	27	9.67098	33	0.32902	9.95686	6	53
8	9.62811	27	9.67131	32	0.32869	9.95680	6	52
9	9.62838	27	9.67163	33	0.32837	9.95674	6	51
10	9.62865	27	9.67196	33	0.32804	9.95668	5	50
11	9.62892	26	9.67229	33	0.32771	9.95663	6	49
12	9.62918	27	9.67262	33	0.32738	9.95657	6	48
13	9.62945	27	9.67295	32	0.32705	9.95651	6	47
14	9.62972	27	9.67327	33	0.32673	9.95645	6	46
15	9.62999	27	9.67360	33	0.32640	9.95639	6	45
16	9.63026	26	9.67393	33	0.32607	9.95633	6	44
17	9.63052	27	9.67426	32	0.32574	9.95627	6	43
18	9.63079	27	9.67458	33	0.32542	9.95621	6	42
19	9.63106	27	9.67491	33	0.32509	9.95615	6	41
20	9.63133	26	9.67524	32	0.32476	9.95609	6	40
21	9.63159	27	9.67556	33	0.32444	9.95603	6	39
22	9.63186	27	9.67589	33	0.32411	9.95597	6	38
23	9.63213	26	9.67622	32	0.32378	9.95591	6	37
24	9.63239	27	9.67654	33	0.32346	9.95585	6	36
25	9.63266	26	9.67687	32	0.32313	9.95579	6	35
26	9.63292	27	9.67719	33	0.32281	9.95573	6	34
27	9.63319	26	9.67752	33	0.32248	9.95567	6	33
28	9.63345	27	9.67785	32	0.32215	9.95561	6	32
29	9.63372	26	9.67817	33	0.32183	9.95555	6	31
30	9.63398	27	9.67850	32	0.32150	9.95549	6	30
31	9.63425	26	9.67882	33	0.32118	9.95543	6	29
32	9.63451	27	9.67915	32	0.32085	9.95537	6	28
33	9.63478	26	9.67947	33	0.32053	9.95531	6	27
34	9.63504	27	9.67980	32	0.32020	9.95525	6	26
35	9.63531	26	9.68012	32	0.31988	9.95519	6	25
36	9.63557	26	9.68044	33	0.31956	9.95513	6	24
37	9.63583	27	9.68077	32	0.31923	9.95507	7	23
38	9.63610	26	9.68109	33	0.31891	9.95500	6	22
39	9.63636	26	9.68142	32	0.31858	9.95494	6	21
40	9.63662	27	9.68174	32	0.31826	9.95488	6	20
41	9.63689	26	9.68206	33	0.31794	9.95482	6	19
42	9.63715	26	9.68239	32	0.31761	9.95476	6	18
43	9.63741	26	9.68271	32	0.31729	9.95470	6	17
44	9.63767	27	9.68303	33	0.31697	9.95464	6	16
45	9.63794	26	9.68336	32	0.31664	9.95458	6	15
46	9.63820	26	9.68368	32	0.31632	9.95452	6	14
47	9.63846	26	9.68400	32	0.31600	9.95446	6	13
48	9.63872	26	9.68432	33	0.31568	9.95440	6	12
49	9.63898	26	9.68465	32	0.31535	9.95434	7	11
50	9.63924	26	9.68497	32	0.31503	9.95427	6	10
51	9.63950	26	9.68529	32	0.31471	9.95421	6	9
52	9.63976	26	9.68561	32	0.31439	9.95415	6	8
53	9.64002	26	9.68593	33	0.31407	9.95409	6	7
54	9.64028	26	9.68626	32	0.31374	9.95403	6	6
55	9.64054	26	9.68658	32	0.31342	9.95397	6	5
56	9.64080	26	9.68690	32	0.31310	9.95391	7	4
57	9.64106	26	9.68722	32	0.31278	9.95384	6	3
58	9.64132	26	9.68754	32	0.31246	9.95378	6	2
59	9.64158	26	9.68786	32	0.31214	9.95372	6	1
60	9.64184		9.68818		0.31182	9.95366		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

P. P.

	33	32
6	3.3	3.2
7	3.9	3.7
8	4.4	4.3
9	5.0	4.8
10	5.5	5.3
20	11.0	10.7
30	16.5	16.0
40	22.0	21.3
50	27.5	26.7

	27
6	2.7
7	3.2
8	3.6
9	4.1
10	4.5
20	9.0
30	13.5
40	18.0
50	22.5

	26
6	2.6
7	3.0
8	3.5
9	3.9
10	4.3
20	8.7
30	13.0
40	17.3
50	21.7

	7
6	0.7
7	0.8
8	0.9
9	1.1
10	1.2
20	2.3
30	3.5
40	4.7
50	5.8

	6	5
6	0.6	0.5
7	0.7	0.6
8	0.8	0.7
9	0.9	0.8
10	1.0	0.8
20	2.0	1.7
30	3.0	2.5
40	4.0	3.3
50	5.0	4.2

P. P.

64°

26°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.64184	26	9.68818	32	0.31182	9.95366	6	60
1	9.64210	26	9.68850	32	0.31150	9.95360	6	59
2	9.64236	26	9.68882	32	0.31118	9.95354	6	58
3	9.64262	26	9.68914	32	0.31086	9.95348	7	57
4	9.64288	25	9.68946	32	0.31054	9.95341	6	56
5	9.64313	26	9.68978	32	0.31022	9.95335	6	55
6	9.64339	26	9.69010	32	0.30990	9.95329	6	54
7	9.64365	26	9.69042	32	0.30958	9.95323	6	53
8	9.64391	26	9.69074	32	0.30926	9.95317	7	52
9	9.64417	25	9.69106	32	0.30894	9.95310	6	51
10	9.64442	26	9.69138	32	0.30862	9.95304	6	50
11	9.64468	26	9.69170	32	0.30830	9.95298	6	49
12	9.64494	25	9.69202	32	0.30798	9.95292	6	48
13	9.64519	26	9.69234	32	0.30766	9.95286	7	47
14	9.64545	26	9.69266	32	0.30734	9.95279	6	46
15	9.64571	25	9.69298	31	0.30702	9.95273	6	45
16	9.64596	26	9.69329	32	0.30671	9.95267	6	44
17	9.64622	25	9.69361	32	0.30639	9.95261	7	43
18	9.64647	26	9.69393	32	0.30607	9.95254	6	42
19	9.64673	25	9.69425	32	0.30575	9.95248	6	41
20	9 64698	26	9.69457	31	0.30543	9.95242	6	40
21	9.64724	25	9.69488	32	0.30512	9.95236	7	39
22	9.64749	26	9.69520	32	0.30480	9.95229	6	38
23	9.64775	25	9.69552	32	0.30448	9.95223	6	37
24	9.64800	26	9.69584	31	0.30416	9.95217	6	36
25	9.64826	25	9.69615	32	0.30385	9.95211	7	35
26	9.64851	26	9.69647	32	0.30353	9.95204	6	34
27	9.64877	25	9.69679	31	0.30321	9.95198	6	33
28	9.64902	25	9.69710	32	0.30290	9.95192	7	32
29	9.64927	26	9.69742	32	0.30258	9.95185	6	31
30	9.64953	25	9.69774	31	0.30226	9.95179	6	30
31	9.64978	25	9.69805	32	0.30195	9.95173	6	29
32	9.65003	26	9.69837	31	0.30163	9.95167	7	28
33	9.65029	25	9.69868	32	0.30132	9.95160	6	27
34	9.65054	25	9.69900	32	0.30100	9.95154	6	26
35	9.65079	25	9.69932	31	0.30068	9.95148	7	25
36	9.65104	26	9.69963	32	0.30037	9.95141	6	24
37	9.65130	25	9.69995	31	0.30005	9.95135	6	23
38	9.65155	25	9.70026	32	0.29974	9.95129	7	22
39	9.65180	25	9.70058	31	0.29942	9.95122	6	21
40	9.65205	25	9.70089	32	0.29911	9.95116	6	20
41	9.65230	25	9.70121	31	0.29879	9.95110	7	19
42	9.65255	26	9.70152	32	0.29848	9.95103	6	18
43	9.65281	25	9.70184	31	0.29816	9.95097	7	17
44	9.65306	25	9.70215	32	0.29785	9.95090	6	16
45	9.65331	25	9.70247	31	0.29753	9.95084	6	15
46	9.65356	25	9.70278	31	0.29722	9.95078	7	14
47	9.65381	25	9.70309	32	0.29691	9.95071	6	13
48	9.65406	25	9.70341	31	0.29659	9.95065	6	12
49	9.65431	25	9.70372	32	0.29628	9.95059	7	11
50	9.65456	25	9.70404	31	0.29596	9.95052	6	10
51	9.65481	25	9.70435	31	0.29565	9.95046	7	9
52	9.65506	25	9.70466	32	0.29534	9.95039	6	8
53	9.65531	25	9.70498	31	0.29502	9.95033	6	7
54	9.65556	24	9.70529	31	0.29471	9.95027	7	6
55	9.65580	25	9.70560	32	0.29440	9.95020	6	5
56	9.65605	25	9.70592	31	0.29408	9.95014	7	4
57	9.65630	25	9.70623	31	0.29377	9.95007	6	3
58	9.65655	25	9.70654	31	0.29346	9.95001	6	2
59	9.65680	25	9.70685	32	0.29315	9.94995	7	1
60	9.65705		9.70717		0.29283	9.94988		0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	d.	′

P. P.

	32	31
6	3.2	3.1
7	3.7	3.6
8	4.3	4.1
9	4.8	4.7
10	5.3	5.2
20	10.7	10.3
30	16.0	15.5
40	21.3	20.7
50	26.7	25.8

	26
6	2.6
7	3.0
8	3.5
9	3.9
10	4.3
20	8.7
30	13.0
40	17.3
50	21.7

	25
6	2.5
7	2.9
8	3.3
9	3.8
10	4.2
20	8.3
30	12.5
40	16.7
50	20.8

	24
6	2.4
7	2.8
8	3.2
9	3.6
10	4.0
20	8.0
30	12.0
40	16.0
50	20.0

	7	6
6	0.7	0.6
7	0.8	0.7
8	0.9	0.8
9	1.1	0.9
10	1.2	1.0
20	2.3	2.0
30	3.5	3.0
40	4.7	4.0
50	5.8	5.0

P. P.

63°

27°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.65705	24	9.70717	31	0.29283	9.94988	6	60
1	9.65729	25	9.70748	31	0.29252	9.94982	7	59
2	9.65754	25	9.70779	31	0.29221	9.94975	6	58
3	9.65779	25	9.70810	31	0.29190	9.94969	7	57
4	9.65804	24	9.70841	32	0.29159	9.94962	6	56
5	9.65828	25	9.70873	31	0.29127	9.94956	7	55
6	9.65853	25	9.70904	31	0.29096	9.94949	6	54
7	9.65878	24	9.70935	31	0.29065	9.94943	7	53
8	9.65902	25	9.70966	31	0.29034	9.94936	6	52
9	9.65927	25	9.70997	31	0.29003	9.94930	7	51
10	9.65952	24	9.71028	31	0.28972	9.94923	6	50
11	9.65976	25	9.71059	31	0.28941	9.94917	6	49
12	9.66001	24	9.71090	31	0.28910	9.94911	7	48
13	9.66025	25	9.71121	32	0.28879	9.94904	6	47
14	9.66050	25	9.71153	31	0.28847	9.94898	7	46
15	9.66075	24	9.71184	31	0.28816	9.94891	6	45
16	9.66099	25	9.71215	31	0.28785	9.94885	7	44
17	9.66124	24	9.71246	31	0.28754	9.94878	7	43
18	9.66148	25	9.71277	31	0.28723	9.94871	6	42
19	9.66173	24	9.71308	31	0.28692	9.94865	7	41
20	9.66197	24	9.71339	31	0.28661	9.94858	6	40
21	9.66221	25	9.71370	31	0.28630	9.94852	7	39
22	9.66246	24	9.71401	30	0.28599	9.94845	6	38
23	9.66270	25	9.71431	31	0.28569	9.94839	7	37
24	9.66295	24	9.71462	31	0.28538	9.94832	6	36
25	9.66319	24	9.71493	31	0.28507	9.94826	7	35
26	9.66343	25	9.71524	31	0.28476	9.94819	6	34
27	9.66368	24	9.71555	31	0.28445	9.94813	7	33
28	9.66392	24	9.71586	31	0.28414	9.94806	7	32
29	9.66416	25	9.71617	31	0.28383	9.94799	6	31
30	9.66441	24	9.71648	31	0.28352	9.94793	7	30
31	9.66465	24	9.71679	30	0.28321	9.94786	6	29
32	9.66489	24	9.71709	31	0.28291	9.94780	7	28
33	9.66513	24	9.71740	31	0.28260	9.94773	6	27
34	9.66537	25	9.71771	31	0.28229	9.94767	7	26
35	9.66562	24	9.71802	31	0.28198	9.94760	7	25
36	9.66586	24	9.71833	30	0.28167	9.94753	6	24
37	9.66610	24	9.71863	31	0.28137	9.94747	7	23
38	9.66634	24	9.71894	31	0.28106	9.94740	6	22
39	9.66658	24	9.71925	30	0.28075	9.94734	7	21
40	9.66682	24	9.71955	31	0.28045	9.94727	7	20
41	9.66706	25	9.71986	31	0.28014	9.94720	6	19
42	9.66731	24	9.72017	31	0.27983	9.94714	7	18
43	9.66755	24	9.72048	30	0.27952	9.94707	7	17
44	9.66779	24	9.72078	31	0.27922	9.94700	6	16
45	9.66803	24	9.72109	31	0.27891	9.94694	7	15
46	9.66827	24	9.72140	30	0.27860	9.94687	7	14
47	9.66851	24	9.72170	31	0.27830	9.94680	6	13
48	9.66875	24	9.72201	30	0.27799	9.94674	7	12
49	9.66899	23	9.72231	31	0.27769	9.94667	7	11
50	9.66922	24	9.72262	31	0.27738	9.94660	6	10
51	9.66946	24	9.72293	30	0.27707	9.94654	7	9
52	9.66970	24	9.72323	31	0.27677	9.94647	7	8
53	9.66994	24	9.72354	30	0.27646	9.94640	6	7
54	9.67018	24	9.72384	31	0.27616	9.94634	7	6
55	9.67042	24	9.72415	30	0.27585	9.94627	7	5
56	9.67066	24	9.72445	31	0.27555	9.94620	6	4
57	9.67090	23	9.72476	30	0.27524	9.94614	7	3
58	9.67113	24	9.72506	31	0.27494	9.94607	7	2
59	9.67137	24	9.72537	30	0.27463	9.94600	7	1
60	9.67161		9.72567		0.27433	9.94593		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

62°

P. P.

	32	31
6	3.2	3.1
7	3.7	3.6
8	4.3	4.1
9	4.8	4.7
10	5.3	5.2
20	10.7	10.3
30	16.0	15.5
40	21.3	20.7
50	26.7	25.8

	30
6	3.0
7	3.5
8	4.0
9	4.5
10	5.0
20	10.0
30	15.0
40	20.0
50	25.0

	25	24
6	2.5	2.4
7	2.9	2.8
8	3.3	3.2
9	3.8	3.6
10	4.2	4.0
20	8.3	8.0
30	12.5	12.0
40	16.7	16.0
50	20.8	20.0

	23
6	2.3
7	2.7
8	3.1
9	3.5
10	3.8
20	7.7
30	11.5
40	15.3
50	19.2

	7	6
6	0.7	0.6
7	0.8	0.7
8	0.9	0.8
9	1.1	0.9
10	1.2	1.0
20	2.3	2.0
30	3.5	3.0
40	4.7	4.0
50	5.8	5.0

P. P.

28°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.67161	24	9.72567	31	0.27433	9.94593	6	60
1	9.67185	23	9.72598	30	0.27402	9.94587	7	59
2	9.67208	24	9.72628	31	0.27372	9.94580	7	58
3	9.67232	24	9.72659	30	0.27341	9.94573	6	57
4	9.67256	24	9.72689	31	0.27311	9.94567	7	56
5	9.67280	23	9.72720	30	0.27280	9.94560	7	55
6	9.67303	24	9.72750	30	0.27250	9.94553	7	54
7	9.67327	23	9.72780	31	0.27220	9.94546	6	53
8	9.67350	24	9.72811	30	0.27189	9.94540	7	52
9	9.67374	24	9.72841	31	0.27159	9.94533	7	51
10	9.67398	23	9.72872	30	0.27128	9.94526	7	50
11	9.67421	24	9.72902	30	0.27098	9.94519	6	49
12	9.67445	23	9.72932	31	0.27068	9.94513	7	48
13	9.67468	24	9.72963	30	0.27037	9.94506	7	47
14	9.67492	23	9.72993	30	0.27007	9.94499	7	46
15	9.67515	24	9.73023	31	0.26977	9.94492	7	45
16	9.67539	23	9.73054	30	0.26946	9.94485	6	44
17	9.67562	24	9.73084	30	0.26916	9.94479	7	43
18	9.67586	23	9.73114	30	0.26886	9.94472	7	42
19	9.67609	24	9.73144	31	0.26856	9.94465	7	41
20	9.67633	23	9.73175	30	0.26825	9.94458	7	40
21	9.67656	24	9.73205	30	0.26795	9.94451	6	39
22	9.67680	23	9.73235	30	0.26765	9.94445	7	38
23	9.67703	23	9.73265	30	0.26735	9.94438	7	37
24	9.67726	24	9.73295	31	0.26705	9.94431	7	36
25	9.67750	23	9.73326	30	0.26674	9.94424	7	35
26	9.67773	23	9.73356	30	0.26644	9.94417	7	34
27	9.67796	24	9.73386	30	0.26614	9.94410	6	33
28	9.67820	23	9.73416	30	0.26584	9.94404	7	32
29	9.67843	23	9.73446	30	0.26554	9.94397	7	31
30	9.67866	24	9.73476	31	0.26524	9.94390	7	30
31	9.67890	23	9.73507	30	0.26493	9.94383	7	29
32	9.67913	23	9.73537	30	0.26463	9.94376	7	28
33	9.67936	23	9.73567	30	0.26433	9.94369	7	27
34	9.67959	23	9.73597	30	0.26403	9.94362	7	26
35	9.67982	24	9.73627	30	0.26373	9.94355	6	25
36	9.68006	23	9.73657	30	0.26343	9.94349	7	24
37	9.68029	23	9.73687	30	0.26313	9.94342	7	23
38	9.68052	23	9.73717	30	0.26283	9.94335	7	22
39	9.68075	23	9.73747	30	0.26253	9.94328	7	21
40	9.68098	23	9.73777	30	0.26223	9.94321	7	20
41	9.68121	23	9.73807	30	0.26193	9.94314	7	19
42	9.68144	23	9.73837	30	0.26163	9.94307	7	18
43	9.68167	23	9.73867	30	0.26133	9.94300	7	17
44	9.68190	23	9.73897	30	0.26103	9.94293	7	16
45	9.68213	24	9.73927	30	0.26073	9.94286	7	15
46	9.68237	23	9.73957	30	0.26043	9.94279	6	14
47	9.68260	23	9.73987	30	0.26013	9.94273	7	13
48	9.68283	22	9.74017	30	0.25983	9.94266	7	12
49	9.68305	23	9.74047	30	0.25953	9.94259	7	11
50	9.68328	23	9.74077	30	0.25923	9.94252	7	10
51	9.68351	23	9.74107	30	0.25893	9.94245	7	9
52	9.68374	23	9.74137	29	0.25863	9.94238	7	8
53	9.68397	23	9.74166	30	0.25834	9.94231	7	7
54	9.68420	23	9.74196	30	0.25804	9.94224	7	6
55	9.68443	23	9.74226	30	0.25774	9.94217	7	5
56	9.68466	23	9.74256	30	0.25744	9.94210	7	4
57	9.68489	23	9.74286	30	0.25714	9.94203	7	3
58	9.68512	22	9.74316	29	0.25684	9.94196	7	2
59	9.68534	23	9.74345	30	0.25655	9.94189	7	1
60	9.68557		9.74375		0.25625	9.94182		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

P. P.

	31	30
6	3.1	3.0
7	3.6	3.5
8	4.1	4.0
9	4.7	4.5
10	5.2	5.0
20	10.3	10.0
30	15.5	15.0
40	20.7	20.0
50	25.8	25.0

	29
6	2.9
7	3.4
8	3.9
9	4.4
10	4.8
20	9.7
30	14.5
40	19.3
50	24.2

	24	23
6	2.4	2.3
7	2.8	2.7
8	3.2	3.1
9	3.6	3.5
10	4.0	3.8
20	8.0	7.7
30	12.0	11.5
40	16.0	15.3
50	20.0	19.2

	22
6	2.2
7	2.6
8	2.9
9	3.3
10	3.7
20	7.3
30	11.0
40	14.7
50	18.3

	7	6
6	0.7	0.6
7	0.8	0.7
8	0.9	0.8
9	1.1	0.9
10	1.2	1.0
20	2.3	2.0
30	3.5	3.0
40	4.7	4.0
50	5.8	5.0

P. P.

61°

29°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	′
0	9.68557	23	9.74375	30	0.25625	9.94182	7	60
1	9.68580	23	9.74405	30	0.25595	9.94175	7	59
2	9.68603	22	9.74435	30	0.25565	9.94168	7	58
3	9.68625	23	9.74465	29	0.25535	9.94161	7	57
4	9.68648	23	9.74494	30	0.25506	9.94154	7	56
5	9.68671	23	9.74524	30	0.25476	9.94147	7	55
6	9.68694	22	9.74554	29	0.25446	9.94140	7	54
7	9.68716	23	9.74583	30	0.25417	9.94133	7	53
8	9.68739	23	9.74613	30	0.25387	9.94126	7	52
9	9.68762	22	9.74643	30	0.25357	9.94119	7	51
10	9.68784	23	9.74673	29	0.25327	9.94112	7	50
11	9.68807	22	9.74702	30	0.25298	9.94105	7	49
12	9.68829	23	9.74732	30	0.25268	9.94098	8	48
13	9.68852	23	9.74762	29	0.25238	9.94090	7	47
14	9.68875	22	9.74791	30	0.25209	9.94083	7	46
15	9.68897	23	9.74821	30	0.25179	9.94076	7	45
16	9.68920	22	9.74851	29	0.25149	9.94069	7	44
17	9.68942	23	9.74880	30	0.25120	9.94062	7	43
18	9.68965	22	9.74910	29	0.25090	9.94055	7	42
19	9.68987	23	9.74939	30	0.25061	9.94048	7	41
20	9.69010	22	9.74969	29	0.25031	9.94041	7	40
21	9.69032	23	9.74998	30	0.25002	9.94034	7	39
22	9.69055	22	9.75028	30	0.24972	9.94027	7	38
23	9.69077	23	9.75058	29	0.24942	9.94020	8	37
24	9.69100	22	9.75087	30	0.24913	9.94012	7	36
25	9.69122	22	9.75117	29	0.24883	9.94005	7	35
26	9.69144	23	9.75146	30	0.24854	9.93998	7	34
27	9.69167	22	9.75176	29	0.24824	9.93991	7	33
28	9.69189	23	9.75205	30	0.24795	9.93984	7	32
29	9.69212	22	9.75235	29	0.24765	9.93977	7	31
30	9.69234	22	9.75264	30	0.24736	9.93970	7	30
31	9.69256	23	9.75294	29	0.24706	9.93963	8	29
32	9.69279	22	9.75323	30	0.24677	9.93955	7	28
33	9.69301	22	9.75353	29	0.24647	9.93948	7	27
34	9.69323	22	9.75382	29	0.24618	9.93941	7	26
35	9.69345	23	9.75411	30	0.24589	9.93934	7	25
36	9.69368	22	9.75441	29	0.24559	9.93927	7	24
37	9.69390	22	9.75470	30	0.24530	9.93920	8	23
38	9.69412	22	9.75500	29	0.24500	9.93912	7	22
39	9.69434	22	9.75529	29	0.24471	9.93905	7	21
40	9.69456	23	9.75558	30	0.24442	9.93898	7	20
41	9.69479	22	9.75588	29	0.24412	9.93891	7	19
42	9.69501	22	9.75617	30	0.24383	9.93884	8	18
43	9.69523	22	9.75647	29	0.24353	9.93876	7	17
44	9.69545	22	9.75676	29	0.24324	9.93869	7	16
45	9.69567	22	9.75705	30	0.24295	9.93862	7	15
46	9.69589	22	9.75735	29	0.24265	9.93855	8	14
47	9.69611	22	9.75764	29	0.24236	9.93847	7	13
48	9.69633	22	9.75793	29	0.24207	9 93840	7	12
49	9.69655	22	9.75822	30	0.24178	9.93833	7	11
50	9.69677	22	9.75852	29	0.24148	9.93826	7	10
51	9.69699	22	9.75881	29	0.24119	9.93819	8	9
52	9.69721	22	9.75910	29	0.24090	9.93811	7	8
53	9.69743	22	9.75939	30	0.24061	9.93804	7	7
54	9.69765	22	9.75969	29	0.24031	9.93797	8	6
55	9.69787	22	9.75998	29	0.24002	9.93789	7	5
56	9.69809	22	9.76027	29	0.23973	9.93782	7	4
57	9.69831	22	9.76056	30	0.23944	9.93775	7	3
58	9.69853	22	9.76086	29	0.23914	9.93768	8	2
59	9.69875	22	9.76115	29	0.23885	9.93760	7	1
60	9.69897		9.76144		0.23856	9.93753		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

P. P.

	30
6	3.0
7	3.5
8	4.0
9	4.5
10	5.0
20	10.0
30	15.0
40	20.0
50	25.0

	29
6	2.9
7	3.4
8	3.9
9	4.4
10	4.8
20	9.7
30	14.5
40	19.3
50	24.2

	23
6	2.3
7	2.7
8	3.1
9	3.5
10	3.8
20	7.7
30	11.5
40	15.3
50	19.2

	22
6	2.2
7	2.6
8	2.9
9	3.3
10	3.7
20	7.3
30	11.0
40	14.7
50	18.3

	8	7
6	0.8	0.7
7	0.9	0.8
8	1.1	0.9
9	1.2	1.1
10	1.3	1.2
20	2.7	2.3
30	4.0	3.5
40	5.3	4.7
50	6.7	5.8

60°

30°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	′
0	9.69897	22	9.76144	29	0.23856	9.93753	7	60
1	9.69919	22	9.76173	29	0.23827	9.93746	8	59
2	9.69941	22	9.76202	29	0.23798	9.93738	7	58
3	9.69963	21	9.76231	30	0.23769	9.93731	7	57
4	9.69984	22	9.76261	29	0.23739	9.93724	7	56
5	9.70006	22	9.76290	29	0.23710	9.93717	8	55
6	9.70028	22	9.76319	29	0.23681	9.93709	7	54
7	9.70050	22	9.76348	29	0.23652	9.93702	7	53
8	9.70072	21	9.76377	29	0.23623	9.93695	8	52
9	9.70093	22	9.76406	29	0.23594	9.93687	7	51
10	9.70115	22	9.76435	29	0.23565	9.93680	7	50
11	9.70137	22	9.76464	29	0.23536	9.93673	8	49
12	9.70159	21	9.76493	29	0.23507	9.93665	7	48
13	9.70180	22	9.76522	29	0.23478	9.93658	8	47
14	9.70202	22	9.76551	29	0.23449	9.93650	7	46
15	9.70224	21	9.76580	29	0.23420	9.93643	7	45
16	9.70245	22	9.76609	30	0.23391	9.93636	8	44
17	9.70267	21	9.76639	29	0.23361	9.93628	7	43
18	9.70288	22	9.76668	29	0.23332	9.93621	7	42
19	9.70310	22	9.76697	28	0.23303	9.93614	8	41
20	9.70332	21	9.76725	29	0.23275	9.93606	7	40
21	9.70353	22	9.76754	29	0.23246	9.93599	8	39
22	9.70375	21	9.76783	29	0.23217	9.93591	7	38
23	9.70396	22	9.76812	29	0.23188	9.93584	7	37
24	9.70418	21	9.76841	29	0.23159	9.93577	8	36
25	9.70439	22	9.76870	29	0.23130	9.93569	7	35
26	9.70461	21	9.76899	29	0.23101	9.93562	8	34
27	9.70482	22	9.76928	29	0.23072	9.93554	7	33
28	9.70504	21	9.76957	29	0.23043	9.93547	8	32
29	9.70525	22	9.76986	29	0.23014	9.93539	7	31
30	9.70547	21	9.77015	29	0.22985	9.93532	7	30
31	9.70568	22	9.77044	29	0.22956	9.93525	8	29
32	9.70590	21	9.77073	28	0.22927	9.93517	7	28
33	9.70611	22	9.77101	29	0.22899	9.93510	8	27
34	9.70633	21	9.77130	29	0.22870	9.93502	7	26
35	9.70654	21	9.77159	29	0.22841	9.93495	8	25
36	9.70675	22	9.77188	29	0.22812	9.93487	7	24
37	9.70697	21	9.77217	29	0.22783	9.93480	8	23
38	9.70718	21	9.77246	28	0.22754	9.93472	7	22
39	9.70739	22	9.77274	29	0.22726	9.93465	8	21
40	9.70761	21	9.77303	29	0.22697	9.93457	7	20
41	9.70782	21	9.77332	29	0.22668	9.93450	8	19
42	9.70803	21	9.77361	29	0.22639	9.93442	7	18
43	9.70824	22	9.77390	28	0.22610	9.93435	8	17
44	9.70846	21	9.77418	29	0.22582	9.93427	7	16
45	9.70867	21	9.77447	29	0.22553	9.93420	8	15
46	9.70888	21	9.77476	29	0.22524	9.93412	7	14
47	9.70909	22	9.77505	28	0.22495	9.93405	8	13
48	9.70931	21	9.77533	29	0.22467	9.93397	7	12
49	9.70952	21	9.77562	29	0.22438	9.93390	8	11
50	9.70973	21	9.77591	28	0.22409	9.93382	7	10
51	9.70994	21	9.77619	29	0.22381	9.93375	8	9
52	9.71015	21	9.77648	29	0.22352	9.93367	7	8
53	9.71036	22	9.77677	29	0.22323	9.93360	8	7
54	9.71058	21	9.77706	28	0.22294	9.93352	8	6
55	9.71079	21	9.77734	29	0.22266	9.93344	7	5
56	9.71100	21	9.77763	28	0.22237	9.93337	8	4
57	9.71121	21	9.77791	29	0.22209	9.93329	7	3
58	9.71142	21	9.77820	29	0.22180	9.93322	8	2
59	9.71163	21	9.77849	28	0.22151	9.93314	7	1
60	9.71184		9.77877		0.22123	9.93307		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

P. P.

	30	29
6	3.0	2.9
7	3.5	3.4
8	4.0	3.9
9	4.5	4.4
10	5.0	4.8
20	10.0	9.7
30	15.0	14.5
40	20.0	19.3
50	25.0	24.2

	28
6	2.8
7	3.3
8	3.7
9	4.2
10	4.7
20	9.3
30	14.0
40	18.7
50	23.3

	22
6	2.2
7	2.6
8	2.9
9	3.3
10	3.7
20	7.3
30	11.0
40	14.7
50	18.3

	21
6	2.1
7	2.5
8	2.8
9	3.2
10	3.5
20	7.0
30	10.5
40	14.0
50	17.5

	8	7
6	0.8	0.7
7	0.9	0.8
8	1.1	0.9
9	1.2	1.1
10	1.3	1.2
20	2.7	2.3
30	4.0	3.5
40	5.3	4.7
50	6.7	5.8

P. P.

59°

31°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.71184	21	9.77877	29	0.22123	9.93307	8	60
1	9.71205	21	9.77906	29	0.22094	9.93299	8	59
2	9.71226	21	9.77935	28	0.22065	9.93291	7	58
3	9.71247	21	9.77963	29	0.22037	9.93284	8	57
4	9.71268	21	9.77992	28	0.22008	9.93276	7	56
5	9.71289	21	9.78020	29	0.21980	9.93269	8	55
6	9.71310	21	9.78049	28	0.21951	9.93261	8	54
7	9.71331	21	9.78077	29	0.21923	9.93253	7	53
8	9.71352	21	9.78106	29	0.21894	9.93246	8	52
9	9.71373	20	9.78135	28	0.21865	9.93238	8	51
10	9.71393	21	9.78163	29	0.21837	9.93230	7	50
11	9.71414	21	9.78192	28	0.21808	9.93223	8	49
12	9.71435	21	9.78220	29	0.21780	9.93215	8	48
13	9.71456	21	9.78249	28	0.21751	9.93207	7	47
14	9.71477	21	9.78277	29	0.21723	9.93200	8	46
15	9.71498	21	9.78306	28	0.21694	9.93192	8	45
16	9.71519	20	9.78334	29	0.21666	9.93184	7	44
17	9.71539	21	9.78363	28	0.21637	9.93177	8	43
18	9.71560	21	9.78391	28	0.21609	9.93169	8	42
19	9.71581	21	9.78419	29	0.21581	9.93161	7	41
20	9.71602	20	9.78448	28	0.21552	9.93154	8	40
21	9.71622	21	9.78476	29	0.21524	9.93146	8	39
22	9.71643	21	9.78505	28	0.21495	9.93138	7	38
23	9.71664	21	9.78533	29	0.21467	9.93131	8	37
24	9.71685	20	9.78562	28	0.21438	9.93123	8	36
25	9.71705	21	9.78590	28	0.21410	9.93115	7	35
26	9.71726	21	9.78618	29	0.21382	9.93108	8	34
27	9.71747	20	9.78647	28	0.21353	9.93100	8	33
28	9.71767	21	9.78675	29	0.21325	9.93092	8	32
29	9.71788	21	9.78704	28	0.21296	9.93084	7	31
30	9.71809	20	9.78732	28	0.21268	9.93077	8	30
31	9.71829	21	9.78760	29	0.21240	9.93069	8	29
32	9.71850	20	9.78789	28	0.21211	9.93061	8	28
33	9.71870	21	9.78817	28	0.21183	9.93053	7	27
34	9.71891	20	9.78845	29	0.21155	9.93046	8	26
35	9.71911	21	9.78874	28	0.21126	9.93038	8	25
36	9.71932	20	9.78902	28	0.21098	9.93030	8	24
37	9.71952	21	9.78930	29	0.21070	9.93022	8	23
38	9.71973	21	9.78959	28	0.21041	9.93014	7	22
39	9.71994	20	9.78987	28	0.21013	9.93007	8	21
40	9.72014	20	9.79015	28	0.20985	9.92999	8	20
41	9.72034	21	9.79043	29	0.20957	9.92991	8	19
42	9.72055	20	9.79072	28	0.20928	9.92983	7	18
43	9.72075	21	9.79100	28	0.20900	9.92976	8	17
44	9.72096	20	9.79128	28	0.20872	9.92968	8	16
45	9.72116	21	9.79156	29	0.20844	9.92960	8	15
46	9.72137	20	9.79185	28	0.20815	9.92952	8	14
47	9.72157	20	9.79213	28	0.20787	9.92944	8	13
48	9.72177	21	9.79241	28	0.20759	9.92936	7	12
49	9.72198	20	9.79269	28	0.20731	9.92929	8	11
50	9.72218	20	9.79297	29	0.20703	9.92921	8	10
51	9.72238	21	9.79326	28	0.20674	9.92913	8	9
52	9.72259	20	9.79354	28	0.20646	9.92905	8	8
53	9.72279	20	9.79382	28	0.20618	9.92897	8	7
54	9.72299	21	9.79410	28	0.20590	9.92889	8	6
55	9.72320	20	9.79438	28	0.20562	9.92881	7	5
56	9.72340	20	9.79466	29	0.20534	9.92874	8	4
57	9.72360	21	9.79495	28	0.20505	9.92866	8	3
58	9.72381	20	9.79523	28	0.20477	9.92858	8	2
59	9.72401	20	9.79551	28	0.20449	9.92850	8	1
60	9.72421		9.79579		0.20421	9.92842		0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	d.	′

P. P.

	29	28	21	20
6	2.9	2.8	2.1	2.0
7	3.4	3.3	2.5	2.3
8	3.9	3.7	2.8	2.7
9	4.4	4.2	3.2	3.0
10	4.8	4.7	3.5	3.3
20	9.7	9.3	7.0	6.7
30	14.5	14.0	10.5	10.0
40	19.3	18.7	14.0	13.3
50	24.2	23.3	17.5	16.7

	8	7
6	0.8	0.7
7	0.9	0.8
8	1.1	0.9
9	1.2	1.1
10	1.3	1.2
20	2.7	2.3
30	4.0	3.5
40	5.3	4.7
50	6.7	5.8

P. P.

58°

32°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.72421	20	9.79579	28	0.20421	9.92842	8	60
1	9.72441	20	9.79607	28	0.20393	9.92834	8	59
2	9.72461	21	9.79635	28	0.20365	9.92826	8	58
3	9.72482	20	9.79663	28	0.20337	9.92818	8	57
4	9.72502	20	9.79691	28	0.20309	9.92810	7	56
5	9.72522	20	9.79719	28	0.20281	9.92803	8	55
6	9.72542	20	9.79747	29	0.20253	9.92795	8	54
7	9.72562	20	9.79776	28	0.20224	9.92787	8	53
8	9.72582	20	9.79804	28	0.20196	9.92779	8	52
9	9.72602	20	9.79832	28	0.20168	9.92771	8	51
10	9.72622	21	9.79860	28	0.20140	9.92763	8	50
11	9.72643	20	9.79888	28	0.20112	9.92755	8	49
12	9.72663	20	9.79916	28	0.20084	9.92747	8	48
13	9.72683	20	9.79944	28	0.20056	9.92739	8	47
14	9.72703	20	9.79972	28	0.20028	9.92731	8	46
15	9.72723	20	9.80000	28	0.20000	9.92723	8	45
16	9.72743	20	9.80028	28	0.19972	9.92715	8	44
17	9.72763	20	9.80056	28	0.19944	9.92707	8	43
18	9.72783	20	9.80084	28	0.19916	9.92699	8	42
19	9.72803	20	9.80112	28	0.19888	9.92691	8	41
20	9.72823	20	9.80140	28	0.19860	9.92683	8	40
21	9.72843	20	9.80168	27	0.19832	9.92675	8	39
22	9.72863	20	9.80195	28	0.19805	9.92667	8	38
23	9.72883	19	9.80223	28	0.19777	9.92659	8	37
24	9.72902	20	9.80251	28	0.19749	9.92651	8	36
25	9.72922	20	9.80279	28	0.19721	9.92643	8	35
26	9.72942	20	9.80307	28	0.19693	9.92635	8	34
27	9.72962	20	9.80335	28	0.19665	9.92627	8	33
28	9.72982	20	9.80363	28	0.19637	9.92619	8	32
29	9.73002	20	9.80391	28	0.19609	9.92611	8	31
30	9.73022	19	9.80419	28	0.19581	9.92603	8	30
31	9.73041	20	9.80447	27	0.19553	9.92595	8	29
32	9.73061	20	9.80474	28	0.19526	9.92587	8	28
33	9.73081	20	9.80502	28	0.19498	9.92579	8	27
34	9.73101	20	9.80530	28	0.19470	9.92571	8	26
35	9.73121	19	9.80558	28	0.19442	9.92563	8	25
36	9.73140	20	9.80586	28	0.19414	9.92555	9	24
37	9.73160	20	9.80614	28	0.19386	9.92546	8	23
38	9.73180	20	9.80642	27	0.19358	9.92538	8	22
39	9.73200	19	9.80669	28	0.19331	9.92530	8	21
40	9.73219	20	9.80697	28	0.19303	9.92522	8	20
41	9.73239	20	9.80725	28	0.19275	9.92514	8	19
42	9.73259	19	9.80753	28	0.19247	9.92506	8	18
43	9.73278	20	9.80781	27	0.19219	9.92498	8	17
44	9.73298	20	9.80808	28	0.19192	9.92490	8	16
45	9.73318	19	9.80836	28	0.19164	9.92482	9	15
46	9.73337	20	9.80864	28	0.19136	9.92473	8	14
47	9.73357	20	9.80892	27	0.19108	9.92465	8	13
48	9.73377	19	9.80919	28	0.19081	9.92457	8	12
49	9.73396	20	9.80947	28	0.19053	9.92449	8	11
50	9.73416	19	9.80975	28	0.19025	9.92441	8	10
51	9.73435	20	9.81003	27	0.18997	9.92433	8	9
52	9.73455	19	9.81030	28	0.18970	9.92425	9	8
53	9.73474	20	9.81058	28	0.18942	9.92416	8	7
54	9.73494	19	9.81086	27	0.18914	9.92408	8	6
55	9.73513	20	9.81113	28	0.18887	9.92400	8	5
56	9.73533	19	9.81141	28	0.18859	9.92392	8	4
57	9.73552	20	9.81169	27	0.18831	9.92384	8	3
58	9.73572	19	9.81196	28	0.18804	9.92376	9	2
59	9.73591	20	9.81224	28	0.18776	9.92367	8	1
60	9.73611		9.81252		0.18748	9.92359		0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	d.	′

P. P.

	29	28
6	2.9	2.8
7	3.4	3.3
8	3.9	3.7
9	4.4	4.2
10	4.8	4.7
20	9.7	9.3
30	14.5	14.0
40	19.3	18.7
50	24.2	23.3

	27
6	2.7
7	3.2
8	3.6
9	4.1
10	4.5
20	9.0
30	13.5
40	18.0
50	22.5

	21	20
6	2.1	2.0
7	2.5	2.3
8	2.8	2.7
9	3.2	3.0
10	3.5	3.3
20	7.0	6.7
30	10.5	10.0
40	14.0	13.3
50	17.5	16.7

	19
6	1.9
7	2.2
8	2.5
9	2.9
10	3.2
20	6.3
30	9.5
40	12.7
50	15.8

	9	8	7
6	0.9	0.8	0.7
7	1.1	0.9	0.8
8	1.2	1.1	0.9
9	1.4	1.2	1.1
10	1.5	1.3	1.2
20	3.0	2.7	2.3
30	4.5	4.0	3.5
40	6.0	5.3	4.7
50	7.5	6.7	5.8

P. P.

57°

33°

'	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.73611	19	9.81252	27	0.18748	9.92359	8	60
1	9.73630	20	9.81279	28	0.18721	9.92351	8	59
2	9.73650	19	9.81307	28	0.18693	9.92343	8	58
3	9.73669	20	9.81335	27	0.18665	9.92335	9	57
4	9.73689	19	9.81362	28	0.18638	9.92326	8	56
5	9.73708	19	9.81390	28	0.18610	9.92318	8	55
6	9.73727	20	9.81418	27	0.18582	9.92310	8	54
7	9.73747	19	9.81445	28	0.18555	9.92302	9	53
8	9.73766	19	9.81473	27	0.18527	9.92293	8	52
9	9.73785	20	9.81500	28	0.18500	9.92285	8	51
10	9.73805	19	9.81528	28	0.18472	9.92277	8	50
11	9.73824	19	9.81556	27	0.18444	9.92269	9	49
12	9.73843	20	9.81583	28	0.18417	9.92260	8	48
13	9.73863	19	9.81611	27	0.18389	9.92252	8	47
14	9.73882	19	9.81638	28	0.18362	9.92244	9	46
15	9.73901	20	9.81666	27	0.18334	9.92235	8	45
16	9.73921	19	9.81693	28	0.18307	9.92227	8	44
17	9.73940	19	9.81721	27	0.18279	9.92219	8	43
18	9.73959	19	9.81748	28	0.18252	9.92211	9	42
19	9.73978	19	9.81776	27	0.18224	9.92202	8	41
20	9.73997	20	9.81803	28	0.18197	9.92194	8	40
21	9.74017	19	9.81831	27	0.18169	9.92186	9	39
22	9.74036	19	9.81858	28	0.18142	9.92177	8	38
23	9.74055	19	9.81886	27	0.18114	9.92169	8	37
24	9.74074	19	9.81913	28	0.18087	9.92161	9	36
25	9.74093	20	9.81941	27	0.18059	9.92152	8	35
26	9.74113	19	9.81968	28	0.18032	9.92144	8	34
27	9.74132	19	9.81996	27	0.18004	9.92136	9	33
28	9.74151	19	9.82023	28	0.17977	9.92127	8	32
29	9.74170	19	9.82051	27	0.17949	9.92119	8	31
30	9.74189	19	9.82078	28	0.17922	9.92111	9	30
31	9.74208	19	9.82106	27	0.17894	9.92102	8	29
32	9.74227	19	9.82133	28	0.17867	9.92094	8	28
33	9.74246	19	9.82161	27	0.17839	9.92086	9	27
34	9.74265	19	9.82188	27	0.17812	9.92077	8	26
35	9.74284	19	9.82215	28	0.17785	9.92069	9	25
36	9.74303	19	9.82243	27	0.17757	9.92060	8	24
37	9.74322	19	9.82270	28	0.17730	9.92052	8	23
38	9.74341	19	9.82298	27	0.17702	9.92044	9	22
39	9.74360	19	9.82325	27	0.17675	9.92035	8	21
40	9.74379	19	9.82352	28	0.17648	9.92027	9	20
41	9.74398	19	9.82380	27	0.17620	9.92018	8	19
42	9.74417	19	9.82407	28	0.17593	9.92010	8	18
43	9.74436	19	9.82435	27	0.17565	9.92002	9	17
44	9.74455	19	9.82462	27	0.17538	9.91993	8	16
45	9.74474	19	9.82489	28	0.17511	9.91985	9	15
46	9.74493	19	9.82517	27	0.17483	9.91976	8	14
47	9.74512	19	9.82544	27	0.17456	9.91968	9	13
48	9.74531	18	9.82571	28	0.17429	9.91959	8	12
49	9.74549	19	9.82599	27	0.17401	9.91951	9	11
50	9.74568	19	9.82626	27	0.17374	9.91942	8	10
51	9.74587	19	9.82653	28	0.17347	9.91934	9	9
52	9.74606	19	9.82681	27	0.17319	9.91925	8	8
53	9.74625	19	9.82708	27	0.17292	9.91917	9	7
54	9.74644	18	9.82735	27	0.17265	9.91908	8	6
55	9.74662	19	9.82762	28	0.17238	9.91900	9	5
56	9.74681	19	9.82790	27	0.17210	9.91891	8	4
57	9.74700	19	9.82817	27	0.17183	9.91883	9	3
58	9.74719	18	9.82844	27	0.17156	9.91874	8	2
59	9.74737	19	9.82871	28	0.17129	9.91866	9	1
60	9.74756		9.82899		0.17101	9.91857		0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	d.	'

P. P.

	28	27
6	2.8	2.7
7	3.3	3.2
8	3.7	3.6
9	4.2	4.1
10	4.7	4.5
20	9.3	9.0
30	14.0	13.5
40	18.7	18.0
50	23.3	22.5

	20
6	2.0
7	2.3
8	2.7
9	3.0
10	3.3
20	6.7
30	10.0
40	13.3
50	16.7

	19
6	1.9
7	2.2
8	2.5
9	2.9
10	3.2
20	6.3
30	9.5
40	12.7
50	15.8

	18
6	1.8
7	2.1
8	2.4
9	2.7
10	3.0
20	6.0
30	9.0
40	12.0
50	15.0

	9	8
6	0.9	0.8
7	1.1	0.9
8	1.2	1.1
9	1.4	1.2
10	1.5	1.3
20	3.0	2.7
30	4.5	4.0
40	6.0	5.3
50	7.5	6.7

P. P.

56°

34°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.74756	19	9.82899	27	0.17101	9.91857	8	60
1	9.74775	19	9.82926	27	0.17074	9.91849	9	59
2	9.74794	18	9.82953	27	0.17047	9.91840	8	58
3	9.74812	19	9.82980	28	0.17020	9.91832	9	57
4	9.74831	19	9.83008	27	0.16992	9.91823	8	56
5	9.74850	18	9.83035	27	0.16965	9.91815	9	55
6	9.74868	19	9.83062	27	0.16938	9.91806	8	54
7	9.74887	19	9.83089	28	0.16911	9.91798	9	53
8	9.74906	18	9.83117	27	0.16883	9.91789	8	52
9	9.74924	19	9.83144	27	0.16856	9.91781	9	51
10	9.74943	18	9.83171	27	0.16829	9.91772	9	50
11	9.74961	19	9.83198	27	0.16802	9.91763	8	49
12	9.74980	19	9.83225	27	0.16775	9.91755	9	48
13	9.74999	18	9.83252	28	0.16748	9.91746	8	47
14	9.75017	19	9.83280	27	0.16720	9.91738	9	46
15	9.75036	18	9.83307	27	0.16693	9.91729	9	45
16	9.75054	19	9.83334	27	0.16666	9.91720	8	44
17	9.75073	18	9.83361	27	0.16639	9.91712	9	43
18	9.75091	19	9.83388	27	0.16612	9.91703	8	42
19	9.75110	18	9.83415	27	0.16585	9.91695	9	41
20	9.75128	19	9.83442	28	0.16558	9.91686	9	40
21	9.75147	18	9.83470	27	0.16530	9.91677	8	39
22	9.75165	19	9.83497	27	0.16503	9.91669	9	38
23	9.75184	18	9.83524	27	0.16476	9.91660	9	37
24	9.75202	19	9.83551	27	0.16449	9.91651	8	36
25	9.75221	18	9.83578	27	0.16422	9.91643	9	35
26	9.75239	19	9.83605	27	0.16395	9.91634	9	34
27	9.75258	18	9.83632	27	0.16368	9.91625	8	33
28	9.75276	18	9.83659	27	0.16341	9.91617	9	32
29	9.75294	19	9.83686	27	0.16314	9.91608	9	31
30	9.75313	18	9.83713	27	0.16287	9.91599	8	30
31	9.75331	19	9.83740	28	0.16260	9.91591	9	29
32	9.75350	18	9.83768	27	0.16232	9.91582	9	28
33	9.75368	18	9.83795	27	0.16205	9.91573	8	27
34	9.75386	19	9.83822	27	0.16178	9.91565	9	26
35	9.75405	18	9.83849	27	0.16151	9.91556	9	25
36	9.75423	18	9.83876	27	0.16124	9.91547	9	24
37	9.75441	18	9.83903	27	0.16097	9.91538	8	23
38	9.75459	19	9.83930	27	0.16070	9.91530	9	22
39	9.75478	18	9.83957	27	0.16043	9.91521	9	21
40	9.75496	18	9.83984	27	0.16016	9.91512	8	20
41	9.75514	19	9.84011	27	0.15989	9.91504	9	19
42	9.75533	18	9.84038	27	0.15962	9.91495	9	18
43	9.75551	18	9.84065	27	0.15935	9.91486	9	17
44	9.75569	18	9.84092	27	0.15908	9.91477	8	16
45	9.75587	18	9.84119	27	0.15881	9.91469	9	15
46	9.75605	19	9.84146	27	0.15854	9.91460	9	14
47	9.75624	18	9.84173	27	0.15827	9.91451	9	13
48	9.75642	18	9.84200	27	0.15800	9.91442	9	12
49	9.75660	18	9.84227	27	0.15773	9.91433	8	11
50	9.75678	18	9.84254	26	0.15746	9.91425	9	10
51	9.75696	18	9.84280	27	0.15720	9.91416	9	9
52	9.75714	19	9.84307	27	0.15693	9.91407	9	8
53	9.75733	18	9.84334	27	0.15666	9.91398	9	7
54	9.75751	18	9.84361	27	0.15639	9.91389	8	6
55	9.75769	18	9.84388	27	0.15612	9.91381	9	5
56	9.75787	18	9.84415	27	0.15585	9.91372	9	4
57	9.75805	18	9.84442	27	0.15558	9.91363	9	3
58	9.75823	18	9.84469	27	0.15531	9.91354	9	2
59	9.75841	18	9.84496	27	0.15504	9.91345	9	1
60	9.75859		9.84523		0.15477	9.91336		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

P. P.

	28	27
6	2.8	2.7
7	3.3	3.2
8	3.7	3.6
9	4.2	4.1
10	4.7	4.5
20	9.3	9.0
30	14.0	13.5
40	18.7	18.0
50	23.3	22.5

	26
6	2.6
7	3.0
8	3.5
9	3.9
10	4.3
20	8.7
30	13.0
40	17.3
50	21.7

	19
6	1.9
7	2.2
8	2.5
9	2.9
10	3.2
20	6.3
30	9.5
40	12.7
50	15.8

	18
6	1.8
7	2.1
8	2.4
9	2.7
10	3.0
20	6.0
30	9.0
40	12.0
50	15.0

	9	8
6	0.9	0.8
7	1.1	0.9
8	1.2	1.1
9	1.4	1.2
10	1.5	1.3
20	3.0	2.7
30	4.5	4.0
40	6.0	5.3
50	7.5	6.7

P. P.

55°

35°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.75859	18	9.84523	27	0.15477	9.91336	8	60
1	9.75877	18	9.84550	26	0.15450	9.91328	9	59
2	9.75895	18	9.84576	27	0.15424	9.91319	9	58
3	9.75913	18	9.84603	27	0.15397	9.91310	9	57
4	9.75931	18	9.84630	27	0.15370	9.91301	9	56
5	9.75949	18	9.84657	27	0.15343	9.91292	9	55
6	9.75967	18	9.84684	27	0.15316	9.91283	9	54
7	9.75985	18	9.84711	27	0.15289	9.91274	8	53
8	9.76003	18	9.84738	26	0.15262	9.91266	9	52
9	9.76021	18	9.84764	27	0.15236	9.91257	9	51
10	9.76039	18	9.84791	27	0.15209	9.91248	9	50
11	9.76057	18	9.84818	27	0.15182	9.91239	9	49
12	9.76075	18	9.84845	27	0.15155	9.91230	9	48
13	9.76093	18	9.84872	27	0.15128	9.91221	9	47
14	9.76111	18	9.84899	26	0.15101	9.91212	9	46
15	9.76129	17	9.84925	27	0.15075	9.91203	9	45
16	9.76146	18	9.84952	27	0.15048	9.91194	9	44
17	9.76164	18	9.84979	27	0.15021	9.91185	9	43
18	9.76182	18	9.85006	27	0.14994	9.91176	9	42
19	9.76200	18	9.85033	26	0.14967	9.91167	9	41
20	9.76218	18	9.85059	27	0.14941	9.91158	9	40
21	9.76236	17	9.85086	27	0.14914	9.91149	8	39
22	9.76253	18	9.85113	27	0.14887	9.91141	9	38
23	9.76271	18	9.85140	26	0.14860	9.91132	9	37
24	9.76289	18	9.85166	27	0.14834	9.91123	9	36
25	9.76307	17	9.85193	27	0.14807	9.91114	9	35
26	9.76324	18	9.85220	27	0.14780	9.91105	9	34
27	9.76342	18	9.85247	26	0.14753	9.91096	9	33
28	9.76360	18	9.85273	27	0.14727	9.91087	9	32
29	9.76378	17	9.85300	27	0.14700	9.91078	9	31
30	9.76395	18	9.85327	27	0.14673	9.91069	9	30
31	9.76413	18	9.85354	26	0.14646	9.91060	9	29
32	9.76431	17	9.85380	27	0.14620	9.91051	9	28
33	9.76448	18	9.85407	27	0.14593	9.91042	9	27
34	9.76466	18	9.85434	26	0.14566	9.91033	10	26
35	9.76484	17	9.85460	27	0.14540	9.91023	9	25
36	9.76501	18	9.85487	27	0.14513	9.91014	9	24
37	9.76519	18	9.85514	26	0.14486	9.91005	9	23
38	9.76537	17	9.85540	27	0.14460	9.90996	9	22
39	9.76554	18	9.85567	27	0.14433	9.90987	9	21
40	9.76572	18	9.85594	26	0.14406	9.90978	9	20
41	9.76590	17	9.85620	27	0.14380	9.90969	9	19
42	9.76607	18	9.85647	27	0.14353	9.90960	9	18
43	9.76625	17	9.85674	26	0.14326	9.90951	9	17
44	9.76642	18	9.85700	27	0.14300	9.90942	9	16
45	9.76660	17	9.85727	27	0.14273	9.90933	9	15
46	9.76677	18	9.85754	26	0.14246	9.90924	9	14
47	9.76695	17	9.85780	27	0.14220	9.90915	9	13
48	9.76712	18	9.85807	27	0.14193	9.90906	10	12
49	9.76730	17	9.85834	26	0.14166	9.90896	9	11
50	9.76747	18	9.85860	27	0.14140	9.90887	9	10
51	9.76765	17	9.85887	26	0.14113	9.90878	9	9
52	9.76782	18	9.85913	27	0.14087	9.90869	9	8
53	9.76800	17	9.85940	27	0.14060	9.90860	9	7
54	9.76817	18	9.85967	26	0.14033	9.90851	9	6
55	9.76835	17	9.85993	27	0.14007	9.90842	10	5
56	9.76852	18	9.86020	26	0.13980	9.90832	9	4
57	9.76870	17	9.86046	27	0.13954	9.90823	9	3
58	9.76887	17	9.86073	27	0.13927	9.90814	9	2
59	9.76904	18	9.86100	26	0.13900	9.90805	9	1
60	9.76922		9.86126		0.13874	9.90796		0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	d.	′

P. P.

	27	26
6	2.7	2.6
7	3.2	3.0
8	3.6	3.5
9	4.1	3.9
10	4.5	4.3
20	9.0	8.7
30	13.5	13.0
40	18.0	17.3
50	22.5	21.7

	18
6	1.8
7	2.1
8	2.4
9	2.7
10	3.0
20	6.0
30	9.0
40	12.0
50	15.0

	17
6	1.7
7	2.0
8	2.3
9	2.6
10	2.8
20	5.7
30	8.5
40	11.3
50	14.2

	10
6	1.0
7	1.2
8	1.3
9	1.5
10	1.7
20	3.3
30	5.0
40	6.7
50	8.3

	9	8
6	0.9	0.8
7	1.1	0.9
8	1.2	1.1
9	1.4	1.2
10	1.5	1.3
20	3.0	2.7
30	4.5	4.0
40	6.0	5.3
50	7.5	6.7

P. P.

54°

36°

'	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.76922	17	9.86126	27	0.13874	9.90796	9	60
1	9.76939	18	9.86153	26	0.13847	9.90787	10	59
2	9.76957	17	9.86179	27	0.13821	9.90777	9	58
3	9.76974	17	9.86206	26	0.13794	9.90768	9	57
4	9.76991	18	9.86232	27	0.13768	9.90759	9	56
5	9.77009	17	9.86259	26	0.13741	9.90750	9	55
6	9.77026	17	9.86285	27	0.13715	9.90741	10	54
7	9.77043	18	9.86312	26	0.13688	9.90731	9	53
8	9.77061	17	9.86338	27	0.13662	9.90722	9	52
9	9.77078	17	9.86365	27	0.13635	9.90713	9	51
10	9.77095	17	9.86392	26	0.13608	9.90704	10	50
11	9.77112	18	9.86418	27	0.13582	9.90694	9	49
12	9.77130	17	9.86445	26	0.13555	9.90685	9	48
13	9.77147	17	9.86471	27	0.13529	9.90676	9	47
14	9.77164	17	9.86498	26	0.13502	9.90667	10	46
15	9.77181	18	9.86524	27	0.13476	9.90657	9	45
16	9.77199	17	9.86551	26	0.13449	9.90648	9	44
17	9.77216	17	9.86577	26	0.13423	9.90639	9	43
18	9.77233	17	9.86603	27	0.13397	9.90630	10	42
19	9.77250	18	9.86630	26	0.13370	9.90620	9	41
20	9.77268	17	9.86656	27	0.13344	9.90611	9	40
21	9.77285	17	9.86683	26	0.13317	9.90602	10	39
22	9.77302	17	9.86709	27	0.13291	9.90592	9	38
23	9.77319	17	9.86736	26	0.13264	9.90583	9	37
24	9.77336	17	9.86762	27	0.13238	9.90574	9	36
25	9.77353	17	9.86789	26	0.13211	9.90565	10	35
26	9.77370	17	9.86815	27	0.13185	9.90555	9	34
27	9.77387	18	9.86842	26	0.13158	9.90546	9	33
28	9.77405	17	9.86868	26	0.13132	9.90537	10	32
29	9.77422	17	9.86894	27	0.13106	9.90527	9	31
30	9.77439	17	9.86921	26	0.13079	9.90518	9	30
31	9.77456	17	9.86947	27	0.13053	9.90509	10	29
32	9.77473	17	9.86974	26	0.13026	9.90499	9	28
33	9.77490	17	9.87000	27	0.13000	9.90490	10	27
34	9.77507	17	9.87027	26	0.12973	9.90480	9	26
35	9.77524	17	9.87053	26	0.12947	9.90471	9	25
36	9.77541	17	9.87079	27	0.12921	9.90462	10	24
37	9.77558	17	9.87106	26	0.12894	9.90452	9	23
38	9.77575	17	9.87132	26	0.12868	9.90443	9	22
39	9.77592	17	9.87158	27	0.12842	9.90434	10	21
40	9.77609	17	9.87185	26	0.12815	9.90424	9	20
41	9.77626	17	9.87211	27	0.12789	9.90415	10	19
42	9.77643	17	9.87238	26	0.12762	9.90405	9	18
43	9.77660	17	9.87264	26	0.12736	9.90396	10	17
44	9.77677	17	9.87290	27	0.12710	9.90386	9	16
45	9.77694	17	9.87317	26	0.12683	9.90377	9	15
46	9.77711	17	9.87343	26	0.12657	9.90368	10	14
47	9.77728	16	9.87369	27	0.12631	9.90358	9	13
48	9.77744	17	9.87396	26	0.12604	9.90349	10	12
49	9.77761	17	9.87422	26	0.12578	9.90339	9	11
50	9.77778	17	9.87448	27	0.12552	9.90330	10	10
51	9.77795	17	9.87475	26	0.12525	9.90320	9	9
52	9.77812	17	9.87501	26	0.12499	9.90311	10	8
53	9.77829	17	9.87527	27	0.12473	9.90301	9	7
54	9.77846	16	9.87554	26	0.12446	9.90292	10	6
55	9.77862	17	9.87580	26	0.12420	9.90282	9	5
56	9.77879	17	9.87606	27	0.12394	9.90273	10	4
57	9.77896	17	9.87633	26	0.12367	9.90263	9	3
58	9.77913	17	9.87659	26	0.12341	9.90254	10	2
59	9.77930	16	9.87685	26	0.12315	9.90244	9	1
60	9.77946		9.87711		0.12289	9.90235		0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin	d.	'

P. P.

	27	26
6	2.7	2.6
7	3.2	3.0
8	3.6	3.5
9	4.1	3.9
10	4.5	4.3
20	9.0	8.7
30	13.5	13.0
40	18.0	17.3
50	22.5	21.7

	18
6	1.8
7	2.1
8	2.4
9	2.7
10	3.0
20	6.0
30	9.0
40	12.0
50	15.0

	17
6	1.7
7	2.0
8	2.3
9	2.6
10	2.8
20	5.7
30	8.5
40	11.3
50	14.2

	16
6	1.6
7	1.9
8	2.1
9	2.4
10	2.7
20	5.3
30	8.0
40	10.7
50	13.3

	10	9
6	1.0	0.9
7	1.2	1.1
8	1.3	1.2
9	1.5	1.4
10	1.7	1.5
20	3.3	3.0
30	5.0	4.5
40	6.7	6.0
50	8.3	7.5

P. P.

53°

37°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.77946		9.87711		0.12289	9.90235		**60**
1	9.77963	17	9.87738	27	0.12262	9.90225	10	59
2	9.77980	17	9.87764	26	0.12236	9.90216	9	58
3	9.77997	17	9.87790	26	0.12210	9.90206	10	57
4	9.78013	16	9.87817	27	0.12183	9.90197	9	56
5	9.78030	17	9.87843	26	0.12157	9.90187	10	55
6	9.78047	17	9.87869	26	0.12131	9.90178	9	54
7	9.78063	16	9.87895	26	0.12105	9.90168	10	53
8	9.78080	17	9.87922	27	0.12078	9.90159	9	52
9	9.78097	17	9.87948	26	0.12052	9.90149	10	51
10	9.78113	16	9.87974	26	0.12026	9.90139	10	**50**
11	9.78130	17	9.88000	26	0.12000	9.90130	9	49
12	9.78147	17	9.88027	27	0.11973	9.90120	10	48
13	9.78163	16	9.88053	26	0.11947	9.90111	9	47
14	9.78180	17	9.88079	26	0.11921	9.90101	10	46
15	9.78197	17	9.88105	26	0.11895	9.90091	10	45
16	9.78213	16	9.88131	26	0.11869	9.90082	9	44
17	9.78230	17	9.88158	27	0.11842	9.90072	10	43
18	9.78246	16	9.88184	26	0.11816	9.90063	9	42
19	9.78263	17	9.88210	26	0.11790	9.90053	10	41
20	9.78280	17	9.88236	26	0.11764	9.90043	10	**40**
21	9.78296	16	9.88262	26	0.11738	9.90034	9	39
22	9.78313	17	9.88289	27	0.11711	9.90024	10	38
23	9.78329	16	9.88315	26	0.11685	9.90014	10	37
24	9.78346	17	9.88341	26	0.11659	9.90005	9	36
25	9.78362	16	9.88367	26	0.11633	9.89995	10	35
26	9.78379	17	9.88393	26	0.11607	9.89985	10	34
27	9.78395	16	9.88420	27	0.11580	9.89976	9	33
28	9.78412	17	9.88446	26	0.11554	9.89966	10	32
29	9.78428	16	9.88472	26	0.11528	9.89956	10	31
30	9.78445	17	9.88498	26	0.11502	9.89947	9	**30**
31	9.78461	16	9.88524	26	0.11476	9.89937	10	29
32	9.78478	17	9.88550	26	0.11450	9.89927	10	28
33	9.78494	16	9.88577	27	0.11423	9.89918	9	27
34	9.78510	16	9.88603	26	0.11397	9.89908	10	26
35	9.78527	17	9.88629	26	0.11371	9.89898	10	25
36	9.78543	16	9.88655	26	0.11345	9.89888	10	24
37	9.78560	17	9.88681	26	0.11319	9.89879	9	23
38	9.78576	16	9.88707	26	0.11293	9.89869	10	22
39	9.78592	16	9.88733	26	0.11267	9.89859	10	21
40	9.78609	17	9.88759	26	0.11241	9.89849	10	**20**
41	9.78625	16	9.88786	27	0.11214	9.89840	9	19
42	9.78642	17	9.88812	26	0.11188	9.89830	10	18
43	9.78658	16	9.88838	26	0.11162	9.89820	10	17
44	9.78674	16	9.88864	26	0.11136	9.89810	10	16
45	9.78691	17	9.88890	26	0.11110	9.89801	9	15
46	9.78707	16	9.88916	26	0.11084	9.89791	10	14
47	9.78723	16	9.88942	26	0.11058	9.89781	10	13
48	9.78739	16	9.88968	26	0.11032	9.89771	10	12
49	9.78756	17	9.88994	26	0.11006	9.89761	10	11
50	9.78772	16	9.89020	26	0.10980	9.89752	9	**10**
51	9.78788	16	9.89046	26	0.10954	9.89742	10	9
52	9.78805	17	9.89073	27	0.10927	9.89732	10	8
53	9.78821	16	9.89099	26	0.10901	9.89722	10	7
54	9.78837	16	9.89125	26	0.10875	9.89712	10	6
55	9.78853	16	9.89151	26	0.10849	9.89702	10	5
56	9.78869	16	9.89177	26	0.10823	9.89693	9	4
57	9.78886	17	9.89203	26	0.10797	9.89683	10	3
58	9.78902	16	9.89229	26	0.10771	9.89673	10	2
59	9.78918	16	9.89255	26	0.10745	9.89663	10	1
60	9.78934	16	9.89281	26	0.10719	9.89653	10	**0**
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	d.	′

P. P.

	27
6	2.7
7	3.2
8	3.6
9	4.1
10	4.5
20	9.0
30	13.5
40	18.0
50	22.5

	26
6	2.6
7	3.0
8	3.5
9	3.9
10	4.3
20	8.7
30	13.0
40	17.3
50	21.7

	17
6	1.7
7	2.0
8	2.3
9	2.6
10	2.8
20	5.7
30	8.5
40	11.3
50	14.2

	16
6	1.6
7	1.9
8	2.1
9	2.4
10	2.7
20	5.3
30	8.0
40	10.7
50	13.3

	10	9
6	1.0	0.9
7	1.2	1.1
8	1.3	1.2
9	1.5	1.4
10	1.7	1.5
20	3.3	3.0
30	5.0	4.5
40	6.7	6.0
50	8.3	7.5

P. P.

52°

38°

′	L. Sin.	d.	L.Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.78934	16	9.89281	26	0.10719	9.89653	10	60
1	9.78950	17	9.89307	26	0.10693	9.89643	10	59
2	9.78967	16	9.89333	26	0.10667	9.89633	9	58
3	9.78983	16	9.89359	26	0.10641	9.89624	10	57
4	9.78999	16	9.89385	26	0.10615	9.89614	10	56
5	9.79015	16	9.89411	26	0.10589	9.89604	10	55
6	9.79031	16	9.89437	26	0.10563	9.89594	10	54
7	9.79047	16	9.89463	26	0.10537	9.89584	10	53
8	9.79063	16	9.89489	26	0.10511	9.89574	10	52
9	9.79079	16	9.89515	26	0.10485	9.89564	10	51
10	9.79095	16	9.89541	26	0.10459	9.89554	10	50
11	9.79111	17	9.89567	26	0.10433	9.89544	10	49
12	9.79128	16	9.89593	26	0.10407	9.89534	10	48
13	9.79144	16	9.89619	26	0.10381	9.89524	10	47
14	9.79160	16	9.89645	26	0.10355	9.89514	10	46
15	9.79176	16	9.89671	26	0.10329	9.89504	9	45
16	9.79192	16	9.89697	26	0.10303	9.89495	10	44
17	9.79208	16	9.89723	26	0.10277	9.89485	10	43
18	9.79224	16	9.89749	26	0.10251	9.89475	10	42
19	9.79240	16	9.89775	26	0.10225	9.89465	10	41
20	9.79256	16	9.89801	26	0.10199	9.89455	10	40
21	9.79272	16	9.89827	26	0.10173	9.89445	10	39
22	9.79288	16	9.89853	26	0.10147	9.89435	10	38
23	9.79304	15	9.89879	26	0.10121	9.89425	10	37
24	9.79319	16	9.89905	26	0.10095	9.89415	10	36
25	9.79335	16	9.89931	26	0.10069	9.89405	10	35
26	9.79351	16	9.89957	26	0.10043	9.89395	10	34
27	9.79367	16	9.89983	26	0.10017	9.89385	10	33
28	9.79383	16	9.90009	26	0.09991	9.89375	11	32
29	9.79399	16	9.90035	26	0.09965	9.89364	10	31
30	9.79415	16	9.90061	25	0.09939	9.89354	10	30
31	9.79431	16	9.90086	26	0.09914	9.89344	10	29
32	9.79447	16	9.90112	26	0.09888	9.89334	10	28
33	9.79463	15	9.90138	26	0.09862	9.89324	10	27
34	9.79478	16	9.90164	26	0.09836	9.89314	10	26
35	9.79494	16	9.90190	26	0.09810	9.89304	10	25
36	9.79510	16	9.90216	26	0.09784	9.89294	10	24
37	9.79526	16	9.90242	26	0.09758	9.89284	10	23
38	9.79542	16	9.90268	26	0.09732	9.89274	10	22
39	9.79558	15	9.90294	26	0.09706	9.89264	10	21
40	9.79573	16	9.90320	26	0.09680	9.89254	10	20
41	9.79589	16	9.90346	25	0.09654	9.89244	11	19
42	9.79605	16	9.90371	26	0.09629	9.89233	10	18
43	9.79621	15	9.90397	26	0.09603	9.89223	10	17
44	9.79636	16	9.90423	26	0.09577	9.89213	10	16
45	9.79652	16	9.90449	26	0.09551	9.89203	10	15
46	9.79668	16	9.90475	26	0.09525	9.89193	10	14
47	9.79684	15	9.90501	26	0.09499	9.89183	10	13
48	9.79699	16	9.90527	26	0.09473	9.89173	11	12
49	9.79715	16	9.90553	25	0.09447	9.89162	10	11
50	9.79731	15	9.90578	26	0.09422	9.89152	10	10
51	9.79746	16	9.90604	26	0.09396	9.89142	10	9
52	9.79762	16	9.90630	26	0.09370	9.89132	10	8
53	9.79778	15	9.90656	26	0.09344	9.89122	10	7
54	9.79793	16	9.90682	26	0.09318	9.89112	11	6
55	9.79809	16	9.90708	26	0.09292	9.89101	10	5
56	9.79825	15	9.90734	25	0.09266	9.89091	10	4
57	9.79840	16	9.90759	26	0.09241	9.89081	10	3
58	9.79856	16	9.90785	26	0.09215	9.89071	11	2
59	9.79872	15	9.90811	26	0.09189	9.89060	10	1
60	9.79887		9.90837		0.09163	9.89050		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

P. P.

	26	25
6	2.6	2.5
7	3.0	2.9
8	3.5	3.3
9	3.9	3.8
10	4.3	4.2
20	8.7	8.3
30	13.0	12.5
40	17.3	16.7
50	21.7	20.8

	17
6	1.7
7	2.0
8	2.3
9	2.6
10	2.8
20	5.7
30	8.5
40	11.3
50	14.2

	16	15
6	1.6	1.5
7	1.9	1.8
8	2.1	2.0
9	2.4	2.3
10	2.7	2.5
20	5.3	5.0
30	8.0	7.5
40	10.7	10.0
50	13.3	12.5

	11
6	1.1
7	1.3
8	1.5
9	1.7
10	1.8
20	3.7
30	5.5
40	7.3
50	9.2

	10	9
6	1.0	0.9
7	1.2	1.1
8	1.3	1.2
9	1.5	1.4
10	1.7	1.5
20	3.3	3.0
30	5.0	4.5
40	6.7	6.0
50	8.3	7.5

P. P.

51°

39°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.79887		9.90837		0.09163	9.89050		60
1	9.79903	16	9.90863	26	0.09137	9.89040	10	59
2	9.79918	15	9.90889	26	0.09111	9.89030	10	58
3	9.79934	16	9.90914	25	0.09086	9.89020	10	57
4	9.79950	16	9.90940	26	0.09060	9.89009	11	56
5	9.79965	15	9.90966	26	0.09034	9.88999	10	55
6	9.79981	16	9.90992	26	0.09008	9.88989	10	54
7	9.79996	15	9.91018	26	0.08982	9.88978	11	53
8	9.80012	16	9.91043	25	0.08957	9.88968	10	52
9	9.80027	15	9.91069	26	0.08931	9.88958	10	51
10	9.80043	16	9.91095	26	0.08905	9.88948	10	50
11	9.80058	15	9.91121	26	0.08879	9.88937	11	49
12	9.80074	16	9.91147	26	0.08853	9.88927	10	48
13	9.80089	15	9.91172	25	0.08828	9.88917	10	47
14	9.80105	16	9.91198	26	0.08802	9.88906	11	46
15	9.80120	15	9.91224	26	0.08776	9.88896	10	45
16	9.80136	16	9.91250	26	0.08750	9.88886	10	44
17	9.80151	15	9.91276	26	0.08724	9.88875	11	43
18	9.80166	15	9.91301	25	0.08699	9.88865	10	42
19	9.80182	16	9.91327	26	0.08673	9.88855	10	41
20	9.80197	15	9.91353	26	0.08647	9.88844	11	40
21	9.80213	16	9.91379	26	0.08621	9.88834	10	39
22	9.80228	15	9.91404	25	0.08596	9.88824	10	38
23	9.80244	16	9.91430	26	0.08570	9.88813	11	37
24	9.80259	15	9.91456	26	0.08544	9.88803	10	36
25	9.80274	15	9.91482	26	0.08518	9.88793	10	35
26	9.80290	16	9.91507	25	0.08493	9.88782	11	34
27	9.80305	15	9.91533	26	0.08467	9.88772	10	33
28	9.80320	15	9.91559	26	0.08441	9.88761	11	32
29	9.80336	16	9.91585	26	0.08415	9.88751	10	31
30	9.80351	15	9.91610	25	0.08390	9.88741	10	30
31	9.80366	15	9.91636	26	0.08364	9.88730	11	29
32	9.80382	16	9.91662	26	0.08338	9.88720	10	28
33	9.80397	15	9.91688	26	0.08312	9.88709	11	27
34	9.80412	15	9.91713	25	0.08287	9.88699	10	26
35	9.80428	16	9.91739	26	0.08261	9.88688	11	25
36	9.80443	15	9.91765	26	0.08235	9.88678	10	24
37	9.80458	15	9.91791	26	0.08209	9.88668	10	23
38	9.80473	15	9.91816	25	0.08184	9.88657	11	22
39	9.80489	16	9.91842	26	0.08158	9.88647	10	21
40	9.80504	15	9.91868	26	0.08132	9.88636	11	20
41	9.80519	15	9.91893	25	0.08107	9.88626	10	19
42	9.80534	15	9.91919	26	0.08081	9.88615	11	18
43	9.80550	16	9.91945	26	0.08055	9.88605	10	17
44	9.80565	15	9.91971	26	0.08029	9.88594	11	16
45	9.80580	15	9.91996	25	0.08004	9.88584	10	15
46	9.80595	15	9.92022	26	0.07978	9.88573	11	14
47	9.80610	15	9.92048	26	0.07952	9.88563	10	13
48	9.80625	15	9.92073	25	0.07927	9.88552	11	12
49	9.80641	16	9.92099	26	0.07901	9.88542	10	11
50	9.80656	15	9.92125	26	0.07875	9.88531	11	10
51	9.80671	15	9.92150	25	0.07850	9.88521	10	9
52	9.80686	15	9.92176	26	0.07824	9.88510	11	8
53	9.80701	15	9.92202	26	0.07798	9.88499	11	7
54	9.80716	15	9.92227	25	0.07773	9.88489	10	6
55	9.80731	15	9.92253	26	0.07747	9.88478	11	5
56	9.80746	15	9.92279	26	0.07721	9.88468	10	4
57	9.80762	16	9.92304	25	0.07696	9.88457	11	3
58	9.80777	15	9.92330	26	0.07670	9.88447	10	2
59	9.80792	15	9.92356	26	0.07644	9.88436	11	1
60	9.80807	15	9.92381	25	0.07619	9.88425	11	0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	d.	′

P. P.

	26	25	16	15	11	10
6	2.6	2.5	1.6	1.5	1.1	1.0
7	3.0	2.9	1.9	1.8	1.3	1.2
8	3.5	3.3	2.1	2.0	1.5	1.3
9	3.9	3.8	2.4	2.3	1.7	1.5
10	4.3	4.2	2.7	2.5	1.8	1.7
20	8.7	8.3	5.3	5.0	3.7	3.3
30	13.0	12.5	8.0	7.5	5.5	5.0
40	17.3	16.7	10.7	10.0	7.3	6.7
50	21.7	20.8	13.3	12.5	9.2	8.3

P. P.

50°

40°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.80807	15	9.92381	26	0.07619	9.88425	10	60
1	9.80822	15	9.92407	26	0.07593	9.88415	11	59
2	9.80837	15	9.92433	25	0.07567	9.88404	10	58
3	9.80852	15	9.92458	26	0.07542	9.88394	11	57
4	9.80867	15	9.92484	26	0.07516	9.88383	11	56
5	9.80882	15	9.92510	25	0.07490	9.88372	10	55
6	9.80897	15	9.92535	26	0.07465	9.88362	11	54
7	9.80912	15	9.92561	26	0.07439	9.88351	11	53
8	9.80927	15	9.92587	25	0.07413	9.88340	10	52
9	9.80942	15	9.92612	26	0.07388	9.88330	11	51
10	9.80957	15	9.92638	25	0.07362	9.88319	11	50
11	9.80972	15	9.92663	26	0.07337	9.88308	10	49
12	9.80987	15	9.92689	26	0.07311	9.88298	11	48
13	9.81002	15	9.92715	25	0.07285	9.88287	11	47
14	9.81017	15	9.92740	26	0.07260	9.88276	10	46
15	9.81032	15	9.92766	26	0.07234	9.88266	11	45
16	9.81047	14	9.92792	25	0.07208	9.88255	11	44
17	9.81061	15	9.92817	26	0.07183	9.88244	10	43
18	9.81076	15	9.92843	25	0.07157	9.88234	11	42
19	9.81091	15	9.92868	26	0.07132	9.88223	11	41
20	9.81106	15	9.92894	26	0.07106	9.88212	11	40
21	9.81121	15	9.92920	25	0.07080	9.88201	10	39
22	9.81136	15	9.92945	26	0.07055	9.88191	11	38
23	9.81151	15	9.92971	25	0.07029	9.88180	11	37
24	9.81166	14	9.92996	26	0.07004	9.88169	11	36
25	9.81180	15	9.93022	26	0.06978	9.88158	10	35
26	9.81195	15	9.93048	25	0.06952	9.88148	11	34
27	9.81210	15	9.93073	26	0.06927	9.88137	11	33
28	9.81225	15	9.93099	25	0.06901	9.88126	11	32
29	9.81240	14	9.93124	26	0.06876	9.88115	10	31
30	9.81254	15	9.93150	25	0.06850	9.88105	11	30
31	9.81269	15	9.93175	26	0.06825	9.88094	11	29
32	9.81284	15	9.93201	26	0.06799	9.88083	11	28
33	9.81299	15	9.93227	25	0.06773	9.88072	11	27
34	9.81314	14	9.93252	26	0.06748	9.88061	10	26
35	9.81328	15	9.93278	25	0.06722	9.88051	11	25
36	9.81343	15	9.93303	26	0.06697	9.88040	11	24
37	9.81358	14	9.93329	25	0.06671	9.88029	11	23
38	9.81372	15	9.93354	26	0.06646	9.88018	11	22
39	9.81387	15	9.93380	26	0.06620	9.88007	11	21
40	9.81402	15	9.93406	25	0.06594	9.87996	11	20
41	9.81417	14	9.93431	26	0.06569	9.87985	10	19
42	9.81431	15	9.93457	25	0.06543	9.87975	11	18
43	9.81446	15	9.93482	26	0.06518	9.87964	11	17
44	9.81461	14	9.93508	25	0.06492	9.87953	11	16
45	9.81475	15	9.93533	26	0.06467	9.87942	11	15
46	9.81490	15	9.93559	25	0.06441	9.87931	11	14
47	9.81505	14	9.93584	26	0.06416	9.87920	11	13
48	9.81519	15	9.93610	26	0.06390	9.87909	11	12
49	9.81534	15	9.93636	25	0.06364	9.87898	11	11
50	9.81549	14	9.93661	26	0.06339	9.87887	10	10
51	9.81563	15	9.93687	25	0.06313	9.87877	11	9
52	9.81578	14	9.93712	26	0.06288	9.87866	11	8
53	9.81592	15	9.93738	25	0.06262	9.87855	11	7
54	9.81607	15	9.93763	26	0.06237	9.87844	11	6
55	9.81622	14	9.93789	25	0.06211	9.87833	11	5
56	9.81636	15	9.93814	26	0.06186	9.87822	11	4
57	9.81651	14	9.93840	25	0.06160	9.87811	11	3
58	9.81665	15	9.93865	26	0.06135	9.87800	11	2
59	9.81680	14	9.93891	25	0.06109	9.87789	11	1
60	9.81694		9.93916		0.06084	9.87778		0
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	d.	′

P. P.

	26	25	15	14
6	2.6	2.5	1.5	1.4
7	3.0	2.9	1.8	1.6
8	3.5	3.3	2.0	1.9
9	3.9	3.8	2.3	2.1
10	4.3	4.2	2.5	2.3
20	8.7	8.3	5.0	4.7
30	13.0	12.5	7.5	7.0
40	17.3	16.7	10.0	9.3
50	21.7	20.8	12.5	11.7

	11	10
6	1.1	1.0
7	1.3	1.2
8	1.5	1.3
9	1.7	1.5
10	1.8	1.7
20	3.7	3.3
30	5.5	5.0
40	7.3	6.7
50	9.2	8.3

P. P.

49°

41°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.81694	15	9.93916	26	0.06084	9.87778	11	60
1	9.81709	14	9.93942	25	0.06058	9.87767	11	59
2	9.81723	15	9.93967	26	0.06033	9.87756	11	58
3	9.81738	14	9.93993	25	0.06007	9.87745	11	57
4	9.81752	15	9.94018	26	0.05982	9.87734	11	56
5	9.81767	14	9.94044	25	0.05956	9.87723	11	55
6	9.81781	15	9.94069	26	0.05931	9.87712	11	54
7	9.81796	14	9.94095	25	0.05905	9.87701	11	53
8	9.81810	15	9.94120	26	0.05880	9.87690	11	52
9	9.81825	14	9.94146	25	0.05854	9.87679	11	51
10	9.81839	15	9.94171	26	0.05829	9.87668	11	50
11	9.81854	14	9.94197	25	0.05803	9.87657	11	49
12	9.81868	14	9.94222	26	0.05778	9.87646	11	48
13	9.81882	15	9.94248	25	0.05752	9.87635	11	47
14	9.81897	14	9.94273	26	0.05727	9.87624	11	46
15	9.81911	15	9.94299	25	0.05701	9.87613	12	45
16	9.81926	14	9.94324	26	0.05676	9.87601	11	44
17	9.81940	15	9.94350	25	0.05650	9.87590	11	43
18	9.81955	14	9.94375	26	0.05625	9.87579	11	42
19	9.81969	14	9.94401	25	0.65599	9.87568	11	41
20	9.81983	15	9.94426	26	0.05574	9.87557	11	40
21	9.81998	14	9.94452	25	0.05548	9.87546	11	39
22	9.82012	14	9.94477	26	0.05523	9.87535	11	38
23	9.82026	15	9.94503	25	0.05497	9.87524	11	37
24	9.82041	14	9.94528	26	0.05472	9.87513	12	36
25	9.82055	14	9.94554	25	0.05446	9.87501	11	35
26	9.82069	15	9.94579	25	0.05421	9.87490	11	34
27	9.82084	14	9.94604	26	0.05396	9.87479	11	33
28	9.82098	14	9.94630	25	0.05370	9.87468	11	32
29	9.82112	14	9.94655	26	0.05345	9.87457	11	31
30	9.82126	15	9.94681	25	0.05319	9.87446	12	30
31	9.82141	14	9.94706	26	0.05294	9.87434	11	29
32	9.82155	14	9.94732	25	0.05268	9.87423	11	28
33	9.82169	15	5.94757	26	0.05243	9.87412	11	27
34	9.82184	14	9.94783	25	0.05217	9.87401	11	26
35	9.82198	14	9.94808	26	0.05192	9.87390	12	25
36	9.82212	14	9.94834	25	0.05166	9.87378	11	24
37	9.82226	14	9.94859	25	0.05141	9.87367	11	23
38	9.82240	15	9.94884	26	0.05116	9.87356	11	22
39	9.82255	14	9.94910	25	0.05090	9.87345	11	21
40	9.82269	14	9.94935	26	0.05065	9.87334	12	20
41	9.82283	14	9.94961	25	0.05039	9.87322	11	19
42	9.82297	14	9.94986	26	0.05014	9.87311	11	18
43	9.82311	15	9.95012	25	0.04988	9.87300	12	17
44	9.82326	14	9.95037	25	0.04963	9.87288	11	16
45	9.82340	14	9.95062	26	0.04938	9.87277	11	15
46	9.82354	14	9.95088	25	0.04912	9.87266	11	14
47	9.82368	14	9.95113	26	0.04887	9.87255	12	13
48	9.82382	14	9.95139	25	0.04861	9.87243	11	12
49	9.82396	14	9.95164	26	0.04836	9.87232	11	11
50	9.82410	14	9.95190	25	0.04810	9.87221	12	10
51	9.82424	15	9.95215	25	0.04785	9.87209	11	9
52	9.82439	14	9.95240	26	0.04760	9.87198	11	8
53	9.82453	14	9.95266	25	0.04734	9.87187	12	7
54	9.82467	14	9.95291	26	0.04709	9.87175	11	6
55	9.82481	14	9.95317	25	0.04683	9.87164	11	5
56	9.82495	14	9.95342	26	0.04658	9.87153	12	4
57	9.82509	14	9.95368	25	0.04632	9.87141	11	3
58	9.82523	14	9.95393	25	0.04607	9.87130	11	2
59	9.82537	14	9.95418	26	0.04582	9.87119	12	1
60	9.82551		9.95444		0.04556	9.87107		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

P. P.

	26	25	15	14	12	11
6	2.6	2.5	1.5	1.4	1.2	1.1
7	3.0	2.9	1 8	1.6	1.4	1.3
8	3.5	3.3	2.0	1.9	1.6	1.5
9	3.9	3.8	2.3	2.1	1.8	1.7
10	4.3	4.2	2.5	2.3	2.0	1.8
20	8.7	8.3	5.0	4.7	4.0	3.7
30	13.0	12.5	7.5	7.0	6.0	5.5
40	17.3	16.7	10.0	9.3	8.0	7.3
50	21.7	20.8	12.5	11.7	10.0	9.2

48°

42°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.82551	14	9.95444	25	0.04556	9.87107	11	60
1	9.82565	14	9.95469	26	0.04531	9.87096	11	59
2	9.82579	14	9.95495	25	0.04505	9.87085	12	58
3	9.82593	14	9.95520	25	0.04480	9.87073	11	57
4	9.82607	14	9.95545	26	0.04455	9.87062	12	56
5	9.82621	14	9.95571	25	0.04429	9.87050	11	55
6	9.82635	14	9.95596	26	0.04404	9.87039	11	54
7	9.82649	14	9.95622	25	0.04378	9.87028	12	53
8	9.82663	14	9.95647	25	0.04353	9.87016	11	52
9	9.82677	14	9.95672	26	0.04328	9.87005	12	51
10	9.82691	14	9.95698	25	0.04302	9.86993	11	50
11	9.82705	14	9.95723	25	0.04277	9.86982	12	49
12	9.82719	14	9.95748	26	0.04252	9.86970	11	48
13	9.82733	14	9.95774	25	0.04226	9.86959	12	47
14	9.82747	14	9.95799	26	0.04201	9.86947	11	46
15	9.82761	14	9.95825	25	0.04175	9.86936	12	45
16	9.82775	13	9.95850	25	0.04150	9.86924	11	44
17	9.82788	14	9.95875	26	0.04125	9.86913	11	43
18	9.82802	14	9.95901	25	0.04099	9.86902	12	42
19	9.82816	14	9.95926	26	0.04074	9.86890	11	41
20	9.82830	14	9.95952	25	0.04048	9.86879	12	40
21	9.82844	14	9.95977	25	0.04023	9.86867	12	39
22	9.82858	14	9.96002	26	0.03998	9.86855	11	38
23	9.82872	13	9.96028	25	0.03972	9.86844	12	37
24	9.82885	14	9.96053	25	0.03947	9.86832	11	36
25	9.82899	14	9.96078	26	0.03922	9.86821	12	35
26	9.82913	14	9.96104	25	0.03896	9.86809	11	34
27	9.82927	14	9.96129	26	0.03871	9.86798	12	33
28	9.82941	14	9.96155	25	0.03845	9.86786	11	32
29	9.82955	13	9.96180	25	0.03820	9.86775	12	31
30	9.82968	14	9.96205	26	0.03795	9.86763	11	30
31	9.82982	14	9.96231	25	0.03769	9.86752	12	29
32	9.82996	14	9.96256	25	0.03744	9.86740	12	28
33	9.83010	13	9.96281	26	0.03719	9.86728	11	27
34	9.83023	14	9.96307	25	0.03693	9.86717	12	26
35	9.83037	14	9.96332	25	0.03668	9.86705	11	25
36	9.83051	14	9.96357	26	0.03643	9.86694	12	24
37	9.83065	13	9.96383	25	0.03617	9.86682	12	23
38	9.83078	14	9.96408	25	0.03592	9.86670	11	22
39	9.83092	14	9.96433	26	0.03567	9.86659	12	21
40	9.83106	14	9.96459	25	0.03541	9.86647	12	20
41	9.83120	13	9.96484	26	0.03516	9.86635	11	19
42	9.83133	14	9.96510	25	0.03490	9.86624	12	18
43	9.83147	14	9.96535	25	0.03465	9.86612	12	17
44	9.83161	13	9.96560	26	0.03440	9.86600	11	16
45	9.83174	14	9.96586	25	0.03414	9.86589	12	15
46	9.83188	14	9.96611	25	0.03389	9.86577	12	14
47	9.83202	13	9.96636	26	0.03364	9.86565	11	13
48	9.83215	14	9.96662	25	0.03338	9.86554	12	12
49	9.83229	13	9.96687	25	0.03313	9.86542	12	11
50	9.83242	14	9.96712	26	0.03288	9.86530	12	10
51	9.83256	14	9.96738	25	0.03262	9.86518	11	9
52	9.83270	13	9.96763	25	0.03237	9.86507	12	8
53	9.83283	14	9.96788	26	0.03212	9.86495	12	7
54	9.83297	13	9.96814	25	0.03186	9.86483	11	6
55	9.83310	14	9.96839	25	0.03161	9.86472	12	5
56	9.83324	14	9.96864	26	0.03136	9.86460	12	4
57	9.83338	13	9.96890	25	0.03110	9.86448	12	3
58	9.83351	14	9.96915	25	0.03085	9.86436	11	2
59	9.83365	13	9.96940	26	0.03060	9.86425	12	1
60	9.83378		9.96966		0.03034	9.86413		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

47°

P. P.

	26	25	14	13
6	2.6	2.5	1.4	1.3
7	3.0	2.9	1.6	1.5
8	3.5	3.3	1.9	1.7
9	3.9	3.8	2.1	2.0
10	4.3	4.2	2.3	2.2
20	8.7	8.3	4.7	4.3
30	13.0	12.5	7.0	6.5
40	17.3	16.7	9.3	8.7
50	21.7	20.8	11.7	10.8

	12	11
6	1.2	1.1
7	1.4	1.3
8	1.6	1.5
9	1.8	1.7
10	2.0	1.8
20	4.0	3.7
30	6.0	5.5
40	8.0	7.3
50	10.0	9.2

P. P.

43°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.	
0	9.83378	14	9.96966	25	0.03034	9.86413	12	60
1	9.83392	13	9.96991	25	0.03009	9.86401	12	59
2	9.83405	14	9.97016	26	0.02984	9.86389	12	58
3	9.83419	13	9.97042	25	0.02958	9.86377	11	57
4	9.83432	14	9.97067	25	0.02933	9.86366	12	56
5	9.83446	13	9.97092	26	0.02908	9.86354	12	55
6	9.83459	14	9.97118	25	0.02882	9.86342	12	54
7	9.83473	13	9.97143	25	0.02857	9.86330	12	53
8	9.83486	14	9.97168	25	0.02832	9.86318	12	52
9	9.83500	13	9.97193	26	0.02807	9.86306	11	51
10	9.83513	14	9.97219	25	0.02781	9.86295	12	50
11	9.83527	13	9.97244	25	0.02756	9.86283	12	49
12	9.83540	14	9.97269	26	0.02731	9.86271	12	48
13	9.83554	13	9.97295	25	0.02705	9.86259	12	47
14	9.83567	14	9.97320	25	0.02680	9.86247	12	46
15	9.83581	13	9.97345	26	0.02655	9.86235	12	45
16	9.83594	14	9.97371	25	0.02629	9.86223	12	44
17	9.83608	13	9.97396	25	0.02604	9.86211	11	43
18	9.83621	13	9.97421	26	0.02579	9.86200	12	42
19	9.83634	14	9.97447	25	0.02553	9.86188	12	41
20	9.83648	13	9.97472	25	0.02528	9.86176	12	40
21	9.83661	13	9.97497	26	0.02503	9.86164	12	39
22	9.83674	14	9.97523	25	0.02477	9.86152	12	38
23	9.83688	13	9.97548	25	0.02452	9.86140	12	37
24	9.83701	14	9.97573	25	0.02427	9.86128	12	36
25	9.83715	13	9.97598	26	0.02402	9.86116	12	35
26	9.83728	13	9.97624	25	0.02376	9.86104	12	34
27	9.83741	14	9.97649	25	0.02351	9.86092	12	33
28	9.83755	13	9.97674	26	0.02326	9.86080	12	32
29	9.83768	13	9.97700	25	0.02300	9.86068	12	31
30	9.83781	14	9.97725	25	0.02275	9.86056	12	30
31	9.83795	13	9.97750	26	0.02250	9.86044	12	29
32	9.83808	13	9.97776	25	0.02224	9.86032	12	28
33	9.83821	13	9.97801	25	0.02199	9.86020	12	27
34	9.83834	14	9.97826	25	0.02174	9.86008	12	26
35	9.83848	13	9.97851	26	0.02149	9.85996	12	25
36	9.83861	13	9.97877	25	0.02123	9.85984	12	24
37	9.83874	13	9.97902	25	0.02098	9.85972	12	23
38	9.83887	14	9.97927	26	0.02073	9.85960	12	22
39	9.83901	13	9.97953	25	0.02047	9.85948	12	21
40	9.83914	13	9.97978	25	0.02022	9.85936	12	20
41	9.83927	13	9.98003	26	0.01997	9.85924	12	19
42	9.83940	14	9.98029	25	0.01971	9.85912	12	18
43	9.83954	13	9.98054	25	0.01946	9.85900	12	17
44	9.83967	13	9.98079	25	0.01921	9.85888	12	16
45	9.83980	13	9.98104	26	0.01896	9.85876	12	15
46	9.83993	13	9.98130	25	0.01870	9.85864	13	14
47	9.84006	14	9.98155	25	0.01845	9.85851	12	13
48	9.84020	13	9.98180	26	0.01820	9.85839	12	12
49	9.84033	13	9.98206	25	0.01794	9.85827	12	11
50	9.84046	13	9.98231	25	0.01769	9.85815	12	10
51	9.84059	13	9.98256	25	0.01744	9.85803	12	9
52	9.84072	13	9.98281	26	0.01719	9.85791	12	8
53	9.84085	13	9.98307	25	0.01693	9.85779	13	7
54	9.84098	14	9.98332	25	0.01668	9.85766	12	6
55	9.84112	13	9.98357	26	0.01643	9.85754	12	5
56	9.84125	13	9.98383	25	0.01617	9.85742	12	4
57	9.84138	13	9.98408	25	0.01592	9.85730	12	3
58	9.84151	13	9.98433	25	0.01567	9.85718	12	2
59	9.84164	13	9.98458	26	0.01542	9.85706	13	1
60	9.84177		9.98484		0.01516	9.85693		0
	L. Cos.	d.	L. Cotg.	d. c.	L.Tang.	L. Sin.	d.	′

46°

P. P.

	26	25	14	13	12	11
6	2.6	2.5	1.4	1.3	1.2	1.1
7	3.0	2.9	1.6	1.5	1.4	1.3
8	3.5	3.3	1.9	1.7	1.6	1.5
9	3.9	3.8	2.1	2.0	1.8	1.7
10	4.3	4.2	2.3	2.2	2.0	1.8
20	8.7	8.3	4.7	4.3	4.0	3.7
30	13.0	12.5	7.0	6.5	6.0	5.5
40	17.3	16.7	9.3	8.7	8.0	7.3
50	21.7	20.8	11.7	10.8	10.0	9.2

44°

′	L. Sin.	d.	L. Tang.	d. c.	L. Cotg.	L. Cos.	d.		P. P.	
0	9.84177	13	9.98484	25	0.01516	9.85693	12	60		
1	9.84190	13	9.98509	25	0.01491	9.85681	12	59		
2	9.84203	13	9.98534	26	0.01466	9.85669	12	58		26
3	9.84216	13	9.98560	25	0.01440	9.85657	12	57	6	2.6
4	9.84229	13	9.98585	25	0.01415	9.85645	13	56	7	3.0
5	9.84242	13	9.98610	25	0.01390	9.85632	12	55	8	3.5
6	9.84255	14	9.98635	26	0.01365	9.85620	12	54	9	3.9
7	9.84269	13	9.98661	25	0.01339	9.85608	12	53	10	4.3
8	9.84282	13	9.98686	25	0.01314	9.85596	13	52	20	8.7
9	9.84295	13	9.98711	26	0.01289	9.85583	12	51	30	13.0
10	9.84308	13	9.98737	25	0.01263	9.85571	12	50	40	17.3
11	9.84321	13	9.98762	25	0.01238	9.85559	12	49	50	21.7
12	9.84334	13	9.98787	25	0.01213	9.85547	13	48		
13	9.84347	13	9.98812	26	0.01188	9.85534	12	47		
14	9.84360	13	9.98838	25	0.01162	9.85522	12	46		25
15	9.84373	12	9.98863	25	0.01137	9.85510	13	45	6	2.5
16	9.84385	13	9.98888	25	0.01112	9.85497	12	44	7	2.9
17	9.84398	13	9.98913	26	0.01087	9.85485	12	43	8	3.3
18	9.84411	13	9.98939	25	0.01061	9.85473	13	42	9	3.8
19	9.84424	13	9.98964	25	0.01036	9.85460	12	41	10	4.2
20	9.84437	13	9.98989	26	0.01011	9.85448	12	40	20	8.3
21	9.84450	13	9.99015	25	0.00985	9.85436	13	39	30	12.5
22	9.84463	13	9.99040	25	0.00960	9.85423	12	38	40	16.7
23	9.84476	13	9.99065	25	0.00935	9.85411	12	37	50	20.8
24	9.84489	13	9.99090	26	0.00910	9.85399	13	36		
25	9.84502	13	9.99116	25	0.00884	9.85386	12	35		
26	9.84515	13	9.99141	25	0.00859	9.85374	13	34		14
27	9.84528	12	9.99166	25	0.00834	9.85361	12	33	6	1.4
28	9.84540	13	9.99191	26	0.00809	9.85349	12	32	7	1.6
29	9.84553	13	9.99217	25	0.00783	9.85337	13	31	8	1.9
30	9.84566	13	9.99242	25	0.00758	9.85324	12	30	9	2.1
31	9.84579	13	9.99267	26	0.00733	9.85312	13	29	10	2.3
32	9.84592	13	9.99293	25	0.00707	9.85299	12	28	20	4.7
33	9.84605	13	9.99318	25	0.00682	9.85287	13	27	30	7.0
34	9.84618	12	9.99343	25	0.00657	9.85274	12	26	40	9.3
35	9.84630	13	9.99368	26	0.00632	9.85262	12	25	50	11.7
36	9.84643	13	9.99394	25	0.00606	9.85250	13	24		
37	9.84656	13	9.99419	25	0.00581	9.85237	12	23		
38	9.84669	13	9.99444	25	0.00556	9.85225	13	22		13
39	9.84682	12	9.99469	26	0.00531	9.85212	12	21	6	1.3
40	9.84694	13	9.99495	25	0.00505	9.85200	13	20	7	1.5
41	9.84707	13	9.99520	25	0.00480	9.85187	12	19	8	1.7
42	9.84720	13	9.99545	25	0.00455	9.85175	13	18	9	2.0
43	9.84733	12	9.99570	26	0.00430	9.85162	12	17	10	2.2
44	9.84745	13	9.99596	25	0.00404	9.85150	13	16	20	4.3
45	9.84758	13	9.99621	25	0.00379	9.85137	12	15	30	6.5
46	9.84771	13	9.99646	26	0.00354	9.85125	13	14	40	8.7
47	9.84784	12	9.99672	25	0.00328	9.85112	12	13	50	10.8
48	9.84796	13	9.99697	25	0.00303	9.85100	13	12		
49	9.84809	13	9.99722	25	0.00278	9.85087	13	11		12
50	9.84822	13	9.99747	26	0.00253	9.85074	12	10	6	1.2
51	9.84835	12	9.99773	25	0.00227	9.85062	13	9	7	1.4
52	9.84847	13	9.99798	25	0.00202	9.85049	12	8	8	1.6
53	9.84860	13	9.99823	25	0.00177	9.85037	13	7	9	1.8
54	9.84873	12	9.99848	26	0.00152	9.85024	12	6	10	2.0
55	9.84885	13	9.99874	25	0.00126	9.85012	13	5	20	4.0
56	9.84898	13	9.99899	25	0.00101	9.84999	13	4	30	6.0
57	9.84911	12	9.99924	25	0.00076	9.84986	12	3	40	8.0
58	9.84923	13	9.99949	26	0.00051	9.84974	13	2	50	10.0
59	9.84936	13	9.99975	25	0.00025	9.84961	12	1		
60	9.84949		0.00000		0.00000	9.84949		0		
	L. Cos.	d.	L. Cotg.	d. c.	L. Tang.	L. Sin.	d.	′	P. P.	

45°

TRAVERSE TABLES.

To use the tables, find the number of degrees in the left-hand column if the angle be less than 45°, and in the right-hand column if greater than 45°. The numbers on the same line running across the page are the latitudes and departures for that angle and for the respective distances, 1, 2, 3, 4, 5, 6, 7, 8, 9, which appear at the top and bottom of the pages. Thus, if the bearing of a line be 10° and the distance 4, the latitude will be 3.939 and the departure 0.695; with the same bearing, and the distance 8, the latitude will be 7.878 and the departure 1.389. The latitude and departure for 80 is 10 times the latitude and departure for 8, and is found by moving the decimal point one place to the right; that for 500 is 100 times the latitude and departure for 5, and is found by moving the decimal point two places to the right and so on. By moving the decimal point one, two, or more places to the right, the latitude and departure may be found for any multiple of any number given in the table. In finding the latitude and departure for any number such as 453, the number is resolved into three numbers, viz.: 400, 50, 3, and the latitude and departure for each taken from the table and then added together.

We thus obtain the following:

Rule.—*Write down the latitude and departure, neglecting the decimal points, for the first figure of the given distance; write under them the latitude and departure for the second figure, setting them one place farther to the right; under these, place the latitude and departure for the third figure, setting them one place still farther to the right, and so continue until all the figures of the given distance have been used; add these latitudes and departures, and point off on the right of their sums a number of decimal places equal to the number of decimal places to which the tables being used are carried; the resulting numbers will be the latitude and departure of the given distance in feet, links, chains, or whatever unit of measurement is adopted.*

EXAMPLE.—A bearing is 16° and the distance 725 ft.; what is the latitude and departure?

Distances.	Latitudes.	Departures.
700	6729	1929
20	1923	0551
5	4806	1378
725	696.936	199.788

Taking the nearest whole numbers and rejecting the decimals, we find the latitude and departure to be 697 and 200.

When a 0 occurs in the given number, the next figure must be set *two* places to the right as in the following example:

The bearing is 22° and the distance 907 ft ; required, the latitude and departure.

Distances.	Latitudes.	Departures.
900	8345	3371
—	—	—
7	6490	2622
907	840.990	339.722

Here the place of 0 both in the distance column and in the latitude and departure columns is occupied by a dash —. Rejecting the decimals, the latitude is 841 ft. and the departure 340 ft. When the bearing is more than 45°, the names of the columns must be read from the bottom of the page. The latitude of any bearing, as 60°, is the departure of its complement, 30°; and the departure of any bearing, as 30°, is the latitude of its complement, 60°. Where the bearings are given in smaller fractions of degrees than is found in the table, the latitudes and departures can be found by interpolation.

Bearing.	1		2		3		4		5	Bearing.
	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	
0°	1.000	0.000	2.000	0.000	3.000	0.000	4.000	0.000	5.000	90°
0¼	1.000	0.004	2.000	0.009	3.000	0.013	4.000	0.017	5.000	89¾
0½	1.000	0.009	2.000	0.017	3.000	0.026	4.000	0.035	5.000	89½
0¾	1.000	0.013	2.000	0.026	3.000	0.039	4.000	0.052	5.000	89¼
1°	1.000	0.017	2.000	0.035	3.000	0.052	3.999	0.070	4.999	89°
1¼	1.000	0.022	2.000	0.044	2.999	0.065	3.999	0.087	4.999	88¾
1½	1.000	0.026	1.999	0.052	2.999	0.079	3.999	0.105	4.998	88½
1¾	1.000	0.031	1.999	0.061	2.999	0.092	3.998	0.122	4.998	88¼
2°	0.999	0.035	1.999	0.070	2.998	0.105	3.998	0.140	4.997	88°
2¼	0.999	0.039	1.998	0.079	2.998	0.118	3.997	0.157	4.996	87¾
2½	0.999	0.044	1.998	0.087	2.997	0.131	3.996	0.174	4.995	87½
2¾	0.999	0.048	1.998	0.096	2.997	0.144	3.995	0.192	4.994	87¼
3°	0.999	0.052	1.997	0.105	2.996	0.157	3.995	0.209	4.993	87°
3¼	0.998	0.057	1.997	0.113	2.995	0.170	3.994	0.227	4.992	86¾
3½	0.998	0.061	1.996	0.122	2.994	0.183	3.993	0.244	4.991	86½
3¾	0.998	0.065	1.996	0.131	2.994	0.196	3.991	0.262	4.989	86¼
4°	0.998	0.070	1.995	0.140	2.993	0.209	3.990	0.279	4.988	86°
4¼	0.997	0.074	1.995	0.148	2.992	0.222	3.989	0.296	4.986	85¾
4½	0.997	0.078	1.994	0.157	2.991	0.235	3.988	0.314	4.985	85½
4¾	0.997	0.083	1.993	0.166	2.990	0.248	3.986	0.331	4.983	85¼
5°	0.996	0.087	1.992	0.174	2.989	0.261	3.985	0.349	4.981	85°
5¼	0.996	0.092	1.992	0.183	2.987	0.275	3.983	0.366	4.979	84¾
5½	0.995	0.096	1.991	0.192	2.986	0.288	3.982	0.383	4.977	84½
5¾	0.995	0.100	1.990	0.200	2.985	0.301	3.980	0.401	4.975	84¼
6°	0.995	0.105	1.989	0.209	2.984	0.314	3.978	0.418	4.973	84°
6¼	0.994	0.109	1.988	0.218	2.982	0.327	3.976	0.435	4.970	83¾
6½	0.994	0.113	1.987	0.226	2.981	0.340	3.974	0.453	4.968	83½
6¾	0.993	0.118	1.986	0.235	2.979	0.353	3.972	0.470	4.965	83¼
7°	0.993	0.122	1.985	0.244	2.978	0.366	3.970	0.487	4.963	83°
7¼	0.992	0.126	1.984	0.252	2.976	0.379	3.968	0.505	4.960	82¾
7½	0.991	0.131	1.983	0.261	2.974	0.392	3.966	0.522	4.957	82½
7¾	0.991	0.135	1.982	0.270	2.973	0.405	3.963	0.539	4.954	82¼
8°	0.990	0.139	1.981	0.278	2.971	0.418	3.961	0.557	4.951	82°
8¼	0.990	0.143	1.979	0.287	2.969	0.430	3.959	0.574	4.948	81¾
8½	0.989	0.148	1.978	0.296	2.967	0.443	3.956	0.591	4.945	81½
8¾	0.988	0.152	1.977	0.304	2.965	0.456	3.953	0.608	4.942	81¼
9°	0.988	0.156	1.975	0.313	2.963	0.469	3.951	0.626	4.938	81°
9¼	0.987	0.161	1.974	0.321	2.961	0.482	3.948	0.643	4.935	80¾
9½	0.986	0.165	1.973	0.330	2.959	0.495	3.945	0.660	4.931	80½
9¾	0.986	0.169	1.971	0.339	2.957	0.508	3.942	0.677	4.928	80¼
10°	0.985	0.174	1.970	0.347	2.954	0.521	3.939	0.695	4.924	80°
10¼	0.984	0.178	1.968	0.356	2.952	0.534	3.936	0.712	4.920	79¾
10½	0.983	0.182	1.967	0.364	2.950	0.547	3.933	0.729	4.916	79½
10¾	0.982	0.187	1.965	0.373	2.947	0.560	3.930	0.746	4.912	79¼
11°	0.982	0.191	1.963	0.382	2.945	0.572	3.927	0.763	4.908	79°
11¼	0.981	0.195	1.962	0.390	2.942	0.585	3.923	0.780	4.904	78¾
11½	0.980	0.199	1.960	0.399	2.940	0.598	3.920	0.797	4.900	78½
11¾	0.979	0.204	1.958	0.407	2.937	0.611	3.916	0.815	4.895	78¼
12°	0.978	0.208	1.956	0.416	2.934	0.624	3.913	0.832	4.891	78°
12¼	0.977	0.212	1.954	0.424	2.932	0.637	3.909	0.849	4.886	77¾
12½	0.976	0.216	1.953	0.433	2.929	0.649	3.905	0.866	4.881	77½
12¾	0.975	0.221	1.951	0.441	2.926	0.662	3.901	0.883	4.877	77¼
13°	0.974	0.225	1.949	0.450	2.923	0.675	3.897	0.900	4.872	77°
	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	
Bearing.	1		2		3		4		5	Bearing.

Bearing.	5	6		7		8		9		Bearing.
	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	
0°	0.000	6.000	0.000	7.000	0.000	8.000	0.000	9.000	0.000	90°
0¼	0.022	6.000	0.026	7.000	0.031	8.000	0.035	9.000	0.039	89¾
0½	0.044	6.000	0.052	7.000	0.061	8.000	0.070	9.000	0.079	89½
0¾	0.065	5.999	0.079	6.999	0.092	7.999	0.105	8.999	0.118	89¼
1°	0.087	5.999	0.105	6.999	0.122	7.999	0.140	8.999	0.157	89°
1¼	0.109	5.999	0.131	6.998	0.153	7.998	0.175	8.998	0.196	88¾
1½	0.131	5.998	0.157	6.998	0.183	7.997	0.209	8.997	0.236	88½
1¾	0.153	5.997	0.183	6.997	0.214	7.996	0.244	8.996	0.275	88¼
2°	0.174	5.996	0.209	6.996	0.244	7.995	0.279	8.995	0.314	88°
2¼	0.196	5.995	0.236	6.995	0.275	7.994	0.314	8.993	0.353	87¾
2½	0.218	5.994	0.262	6.993	0.305	7.992	0.349	8.991	0.393	87½
2¾	0.240	5.993	0.288	6.992	0.336	7.991	0.384	8.990	0.432	87¼
3°	0.262	5.992	0.314	6.990	0.366	7.989	0.419	8.988	0.471	87°
3¼	0.283	5.990	0.340	6.989	0.397	7.987	0.454	8.986	0.510	86¾
3½	0.305	5.989	0.366	6.987	0.427	7.985	0.488	8.983	0.549	86½
3¾	0.327	5.987	0.392	6.985	0.458	7.983	0.523	8.981	0.589	86¼
4°	0.349	5.985	0.419	6.983	0.488	7.981	0.558	8.978	0.628	86°
4¼	0.371	5.984	0.445	6.981	0.519	7.978	0.593	8.975	0.667	85¾
4½	0.392	5.982	0.471	6.978	0.549	7.975	0.628	8.972	0.706	85½
4¾	0.414	5.979	0.497	6.976	0.580	7.973	0.662	8.969	0.745	85¼
5°	0.436	5.977	0.523	6.973	0.610	7.970	0.697	8.966	0.784	85°
5¼	0.458	5.975	0.549	6.971	0.641	7.966	0.732	8.962	0.824	84¾
5½	0.479	5.972	0.575	6.968	0.671	7.963	0.767	8.959	0.863	84½
5¾	0.501	5.970	0.601	6.965	0.701	7.960	0.802	8.955	0.902	84¼
6°	0.523	5.967	0.627	6.962	0.732	7.956	0.836	8.951	0.941	84°
6¼	0.544	5.964	0.653	6.958	0.762	7.952	0.871	8.947	0.980	83¾
6½	0.566	5.961	0.679	6.955	0.792	7.949	0.906	8.942	1.019	83½
6¾	0.588	5.958	0.705	6.951	0.823	7.945	0.940	8.938	1.058	83¼
7°	0.609	5.955	0.731	6.948	0.853	7.940	0.975	8.933	1.097	83°
7¼	0.631	5.952	0.757	6.944	0.883	7.936	1.010	8.928	1.136	82¾
7½	0.653	5.949	0.783	6.940	0.914	7.932	1.044	8.923	1.175	82½
7¾	0.674	5.945	0.809	6.936	0.944	7.927	1.079	8.918	1.214	82¼
8°	0.696	5.942	0.835	6.932	0.974	7.922	1.113	8.912	1.253	82°
8¼	0.717	5.938	0.861	6.928	1.004	7.917	1.148	8.907	1.291	81¾
8½	0.739	5.934	0.887	6.923	1.035	7.912	1.182	8.901	1.330	81½
8¾	0.761	5.930	0.913	6.919	1.065	7.907	1.217	8.895	1.369	81¼
9°	0.782	5.926	0.939	6.914	1.095	7.902	1.251	8.889	1.408	81°
9¼	0.804	5.922	0.964	6.909	1.125	7.896	1.286	8.883	1.447	80¾
9½	0.825	5.918	0.990	6.904	1.155	7.890	1.320	8.877	1.485	80½
9¾	0.847	5.913	1.016	6.899	1.185	7.884	1.355	8.870	1.524	80¼
10°	0.868	5.909	1.042	6.894	1.216	7.878	1.389	8.863	1.563	80°
10¼	0.890	5.904	1.068	6.888	1.246	7.872	1.424	8.856	1.601	79¾
10½	0.911	5.900	1.093	6.883	1.276	7.866	1.458	8.849	1.640	79½
10¾	0.933	5.895	1.119	6.877	1.306	7.860	1.492	8.842	1.679	79¼
11°	0.954	5.890	1.145	6.871	1.336	7.853	1.526	8.835	1.717	79°
11¼	0.975	5.885	1.171	6.866	1.366	7.846	1.561	8.827	1.756	78¾
11½	0.997	5.880	1.196	6.859	1.396	7.839	1.595	8.819	1.794	78½
11¾	1.018	5.874	1.222	6.853	1.425	7.832	1.629	8.811	1.833	78¼
12°	1.040	5.869	1.247	6.847	1.455	7.825	1.663	8.803	1.871	78°
12¼	1.061	5.863	1.273	6.841	1.485	7.818	1.697	8.795	1.910	77¾
12½	1.082	5.858	1.299	6.834	1.515	7.810	1.732	8.787	1.948	77½
12¾	1.103	5.852	1.324	6.827	1.545	7.803	1.766	8.778	1.986	77¼
13°	1.125	5.846	1.350	6.821	1.575	7.795	1.800	8.769	2.025	77°
Bearing.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Bearing.
	5	6		7		8		9		

Bearing.	1		2		3		4		5	Bearing.
	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	
13°	0.974	0.225	1.949	0.450	2.923	0.675	3.897	0.900	4.872	77°
13¼	0.973	0.229	1.947	0.458	2.920	0.688	3.894	0.917	4.867	76¾
13½	0.972	0.233	1.945	0.467	2.917	0.700	3.889	0.934	4.862	76½
13¾	0.971	0.238	1.943	0.475	2.914	0.713	3.885	0.951	4.857	76¼
14°	0.970	0.242	1.941	0.484	2.911	0.726	3.881	0.968	4.851	76°
14¼	0.969	0.246	1.938	0.492	2.908	0.738	3.877	0.985	4.846	75¾
14½	0.968	0.250	1.936	0.501	2.904	0.751	3.873	1.002	4.841	75½
14¾	0.967	0.255	1.934	0.509	2.901	0.764	3.868	1.018	4.835	75¼
15°	0.966	0.259	1.932	0.518	2.898	0.776	3.864	1.035	4.830	75°
15¼	0.965	0.263	1.930	0.526	2.894	0.789	3.859	1.052	4.824	74¾
15½	0.964	0.267	1.927	0.534	2.891	0.802	3.855	1.069	4.818	74½
15¾	0.962	0.271	1.925	0.543	2.887	0.814	3.850	1.086	4.812	74¼
16°	0.961	0.276	1.923	0.551	2.884	0.827	3.845	1.103	4.806	74°
16¼	0.960	0.280	1.920	0.560	2.880	0.839	3.840	1.119	4.800	73¾
16½	0.959	0.284	1.918	0.568	2.876	0.852	3.835	1.136	4.794	73½
16¾	0.958	0.288	1.915	0.576	2.873	0.865	3.830	1.153	4.788	73¼
17°	0.956	0.292	1.913	0.585	2.869	0.877	3.825	1.169	4.782	73°
17¼	0.955	0.297	1.910	0.593	2.865	0.890	3.820	1.186	4.775	72¾
17½	0.954	0.301	1.907	0.601	2.861	0.902	3.815	1.203	4.769	72½
17¾	0.952	0.305	1.905	0.610	2.857	0.915	3.810	1.220	4.762	72¼
18°	0.951	0.309	1.902	0.618	2.853	0.927	3.804	1.236	4.755	72°
18¼	0.950	0.313	1.899	0.626	2.849	0.939	3.799	1.253	4.748	71¾
18½	0.948	0.317	1.897	0.635	2.845	0.952	3.793	1.269	4.742	71½
18¾	0.947	0.321	1.894	0.643	2.841	0.964	3.788	1.286	4.735	71¼
19°	0.946	0.326	1.891	0.651	2.837	0.977	3.782	1.302	4.728	71°
19¼	0.944	0.330	1.888	0.659	2.832	0.989	3.776	1.319	4.720	70¾
19½	0.943	0.334	1.885	0.668	2.828	1.001	3.771	1.335	4.713	70½
19¾	0.941	0.338	1.882	0.676	2.824	1.014	3.765	1.352	4.706	70¼
20°	0.940	0.342	1.879	0.684	2.819	1.026	3.759	1.368	4.698	70°
20¼	0.938	0.346	1.876	0.692	2.815	1.038	3.753	1.384	4.691	69¾
20½	0.937	0.350	1.873	0.700	2.810	1.051	3.747	1.401	4.683	69½
20¾	0.935	0.354	1.870	0.709	2.805	1.063	3.741	1.417	4.676	69¼
21°	0.934	0.358	1.867	0.717	2.801	1.075	3.734	1.433	4.668	69°
21¼	0.932	0.362	1.864	0.725	2.796	1.087	3.728	1.450	4.660	68¾
21½	0.930	0.367	1.861	0.733	2.791	1.100	3.722	1.466	4.652	68½
21¾	0.929	0.371	1.858	0.741	2.786	1.112	3.715	1.482	4.644	68¼
22°	0.927	0.375	1.854	0.749	2.782	1.124	3.709	1.498	4.636	68°
22¼	0.926	0.379	1.851	0.757	2.777	1.136	3.702	1.515	4.628	67¾
22½	0.924	0.383	1.848	0.765	2.772	1.148	3.696	1.531	4.619	67½
22¾	0.922	0.387	1.844	0.773	2.767	1.160	3.689	1.547	4.611	67¼
23°	0.921	0.391	1.841	0.781	2.762	1.172	3.682	1.563	4.603	67°
23¼	0.919	0.395	1.838	0.789	2.756	1.184	3.675	1.579	4.594	66¾
23½	0.917	0.399	1.834	0.797	2.751	1.196	3.668	1.595	4.585	66½
23¾	0.915	0.403	1.831	0.805	2.746	1.208	3.661	1.611	4.577	66¼
24°	0.914	0.407	1.827	0.813	2.741	1.220	3.654	1.627	4.568	66°
24¼	0.912	0.411	1.824	0.821	2.735	1.232	3.647	1.643	4.559	65¾
24½	0.910	0.415	1.820	0.829	2.730	1.244	3.640	1.659	4.550	65½
24¾	0.908	0.419	1.816	0.837	2.724	1.256	3.633	1.675	4.541	65¼
25°	0.906	0.423	1.813	0.845	2.719	1.268	3.625	1.690	4.532	65°
25¼	0.904	0.427	1.809	0.853	2.713	1.280	3.618	1.706	4.522	64¾
25½	0.903	0.431	1.805	0.861	2.708	1.292	3.610	1.722	4.513	64½
25¾	0.901	0.434	1.801	0.869	2.702	1.303	3.603	1.738	4.503	64¼
26°	0.899	0.438	1.798	0.877	2.696	1.315	3.595	1.753	4.494	64°
	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	
Bearing.	1		2		3		4		5	Bearing.

Bearing.	5	6		7		8		9		Bearing.
	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	
13°	1.125	5.846	1.350	6.821	1.575	7.795	1.800	8.769	2.025	77°
13¼	1.146	5.840	1.375	6.814	1.604	7.787	1.834	8.760	2.063	76¾
13½	1.167	5.834	1.401	6.807	1.634	7.779	1.868	8.751	2.101	76½
13¾	1.188	5.828	1.426	6.799	1.664	7.771	1.902	8.742	2.139	76¼
14°	1.210	5.822	1.452	6.792	1.693	7.762	1.935	8.733	2.177	76°
14¼	1.231	5.815	1.477	6.785	1.723	7.754	1.969	8.723	2.215	75¾
14½	1.252	5.809	1.502	6.777	1.753	7.745	2.003	8.713	2.253	75½
14¾	1.273	5.802	1.528	6.769	1.782	7.736	2.037	8.703	2.291	75¼
15°	1.294	5.796	1.553	6.761	1.812	7.727	2.071	8.693	2.329	75°
15¼	1.315	5.789	1.578	6.754	1.841	7.718	2.104	8.683	2.367	74¾
15½	1.336	5.782	1.603	6.745	1.871	7.709	2.138	8.673	2.405	74½
15¾	1.357	5.775	1.629	6.737	1.900	7.700	2.172	8.662	2.443	74¼
16°	1.378	5.768	1.654	6.729	1.929	7.690	2.205	8.651	2.481	74°
16¼	1.399	5.760	1.679	6.720	1.959	7.680	2.239	8.640	2.518	73¾
16½	1.420	5.753	1.704	6.712	1.988	7.671	2.272	8.629	2.556	73½
16¾	1.441	5.745	1.729	6.703	2.017	7.661	2.306	8.618	2.594	73¼
17°	1.462	5.738	1.754	6.694	2.047	7.650	2.339	8.607	2.631	73°
17¼	1.483	5.730	1.779	6.685	2.076	7.640	2.372	8.595	2.669	72¾
17½	1.504	5.722	1.804	6.676	2.105	7.630	2.406	8.583	2.706	72½
17¾	1.524	5.714	1.829	6.667	2.134	7.619	2.439	8.572	2.744	72¼
18°	1.545	5.706	1.854	6.657	2.163	7.608	2.472	8.560	2.781	72°
18¼	1.566	5.698	1.879	6.648	2.192	7.598	2.505	8.547	2.818	71¾
18½	1.587	5.690	1.904	6.638	2.221	7.587	2.538	8.535	2.856	71½
18¾	1.607	5.682	1.929	6.629	2.250	7.575	2.572	8.522	2.893	71¼
19°	1.628	5.673	1.953	6.619	2.279	7.564	2.605	8.510	2.930	71°
19¼	1.648	5.665	1.978	6.609	2.308	7.553	2.638	8.497	2.967	70¾
19½	1.669	5.656	2.003	6.598	2.337	7.541	2.670	8.484	3.004	70½
19¾	1.690	5.647	2.028	6.588	2.365	7.529	2.703	8.471	3.041	70¼
20°	1.710	5.638	2.052	6.578	2.394	7.518	2.736	8.457	3.078	70°
20¼	1.731	5.629	2.077	6.567	2.423	7.506	2.769	8.444	3.115	69¾
20½	1.751	5.620	2.101	6.557	2.451	7.493	2.802	8.430	3.152	69½
20¾	1.771	5.611	2.126	6.546	2.480	7.481	2.834	8.416	3.189	69¼
21°	1.792	5.601	2.150	6.535	2.509	7.469	2.867	8.402	3.225	69°
21¼	1.812	5.592	2.175	6.524	2.537	7.456	2.900	8.388	3.262	68¾
21½	1.833	5.582	2.199	6.513	2.566	7.443	2.932	8.374	3.299	68½
21¾	1.853	5.573	2.223	6.502	2.594	7.430	2.964	8.359	3.335	68¼
22°	1.873	5.563	2.248	6.490	2.622	7.417	2.997	8.345	3.371	68°
22¼	1.893	5.553	2.272	6.479	2.651	7.404	3.029	8.330	3.408	67¾
22½	1.913	5.543	2.296	6.467	2.679	7.391	3.061	8.315	3.444	67½
22¾	1.934	5.533	2.320	6.455	2.707	7.378	3.094	8.300	3.480	67¼
23°	1.954	5.523	2.344	6.444	2.735	7.364	3.126	8.285	3.517	67°
23¼	1.974	5.513	2.368	6.432	2.763	7.350	3.158	8.269	3.553	66¾
23½	1.994	5.502	2.392	6.419	2.791	7.336	3.190	8.254	3.589	66½
23¾	2.014	5.492	2.416	6.407	2.819	7.322	3.222	8.238	3.625	66¼
24°	2.034	5.481	2.440	6.395	2.847	7.308	3.254	8.222	3.661	66°
24¼	2.054	5.471	2.464	6.382	2.875	7.294	3.286	8.206	3.696	65¾
24½	2.073	5.460	2.488	6.370	2.903	7.280	3.318	8.190	3.732	65½
24¾	2.093	5.449	2.512	6.357	2.931	7.265	3.349	8.173	3.768	65¼
25°	2.113	5.438	2.536	6.344	2.958	7.250	3.381	8.157	3.804	65°
25¼	2.133	5.427	2.559	6.331	2.986	7.236	3.413	8.140	3.839	64¾
25½	2.153	5.416	2.583	6.318	3.014	7.221	3.444	8.123	3.875	64½
25¾	2.172	5.404	2.607	6.305	3.041	7.206	3.476	8.106	3.910	64¼
26°	2.192	5.393	2.630	6.292	3.069	7.190	3.507	8.089	3.945	64°
	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	
Bearing.	5	6		7		8		9		Bearing.

Bearing.	1 Lat.	1 Dep.	2 Lat.	2 Dep.	3 Lat.	3 Dep.	4 Lat.	4 Dep.	5 Lat.	Bearing.
26°	0.899	0.438	1.798	0.877	2.696	1.315	3.595	1.753	4.494	**64°**
26¼	0.897	0.442	1.794	0.885	2.691	1.327	3.587	1.769	4.484	63¾
26½	0.895	0.446	1.790	0.892	2.685	1.339	3.580	1.785	4.475	63½
26¾	0.893	0.450	1.786	0.900	2.679	1.350	3.572	1.800	4.465	63¼
27°	0.891	0.454	1.782	0.908	2.673	1.362	3.564	1.816	4.455	**63°**
27¼	0.889	0.458	1.778	0.916	2.667	1.374	3.556	1.831	4.445	62¾
27½	0.887	0.462	1.774	0.923	2.661	1.385	3.548	1.847	4.435	62½
27¾	0.885	0.466	1.770	0.931	2.655	1.397	3.540	1.862	4.425	62¼
28°	0.883	0.469	1.766	0.939	2.649	1.408	3.532	1.878	4.415	**62°**
28¼	0.881	0.473	1.762	0.947	2.643	1.420	3.524	1.893	4.404	61¾
28½	0.879	0.477	1.758	0.954	2.636	1.431	3.515	1.909	4.394	61½
28¾	0.877	0.481	1.753	0.962	2.630	1.443	3.507	1.924	4.384	61¼
29°	0.875	0.485	1.749	0.970	2.624	1.454	3.498	1.939	4.373	**61°**
29¼	0.872	0.489	1.745	0.977	2.617	1.466	3.490	1.954	4.362	60¾
29½	0.870	0.492	1.741	0.985	2.611	1.477	3.481	1.970	4.352	60½
29¾	0.868	0.496	1.736	0.992	2.605	1.489	3.473	1.985	4.341	60¼
30°	0.866	0.500	1.732	1.000	2.598	1.500	3.464	2.000	4.330	**60°**
30¼	0.864	0.504	1.728	1.008	2.592	1.511	3.455	2.015	4.319	59¾
30½	0.862	0.508	1.723	1.015	2.585	1.523	3.447	2.030	4.308	59½
30¾	0.859	0.511	1.719	1.023	2.578	1.534	3.438	2.045	4.297	59¼
31°	0.857	0.515	1.714	1.030	2.572	1.545	3.429	2.060	4.286	**59°**
31¼	0.855	0.519	1.710	1.038	2.565	1.556	3.420	2.075	4.275	58¾
31½	0.853	0.522	1.705	1.045	2.558	1.567	3.411	2.090	4.263	58½
31¾	0.850	0.526	1.701	1.052	2.551	1.579	3.401	2.105	4.252	58¼
32°	0.848	0.530	1.696	1.060	2.544	1.590	3.392	2.120	4.240	**58°**
32¼	0.846	0.534	1.691	1.067	2.537	1.601	3.383	2.134	4.229	57¾
32½	0.843	0.537	1.687	1.075	2.530	1.612	3.374	2.149	4.217	57½
32¾	0.841	0.541	1.682	1.082	2.523	1.623	3.364	2.164	4.205	57¼
33°	0.839	0.545	1.677	1.089	2.516	1.634	3.355	2.179	4.193	**57°**
33¼	0.836	0.548	1.673	1.097	2.509	1.645	3.345	2.193	4.181	56¾
33½	0.834	0.552	1.668	1.104	2.502	1.656	3.336	2.208	4.169	56½
33¾	0.831	0.556	1.663	1.111	2.494	1.667	3.326	2.222	4.157	56¼
34°	0.829	0.559	1.658	1.118	2.487	1.678	3.316	2.237	4.145	**56°**
34¼	0.827	0.563	1.653	1.126	2.480	1.688	3.306	2.251	4.133	55¾
34½	0.824	0.566	1.648	1.133	2.472	1.699	3.297	2.266	4.121	55½
34¾	0.822	0.570	1.643	1.140	2.465	1.710	3.287	2.280	4.108	55¼
35°	0.819	0.574	1.638	1.147	2.457	1.721	3.277	2.294	4.096	**55°**
35¼	0.817	0.577	1.633	1.154	2.450	1.731	3.267	2.309	4.083	54¾
35½	0.814	0.581	1.628	1.161	2.442	1.742	3.257	2.323	4.071	54½
35¾	0.812	0.584	1.623	1.168	2.435	1.753	3.246	2.337	4.058	54¼
36°	0.809	0.588	1.618	1.176	2.427	1.763	3.236	2.351	4.045	**54°**
36¼	0.806	0.591	1.613	1.183	2.419	1.774	3.226	2.365	4.032	53¾
36½	0.804	0.595	1.608	1.190	2.412	1.784	3.215	2.379	4.019	53½
36¾	0.801	0.598	1.603	1.197	2.404	1.795	3.205	2.393	4.006	53¼
37°	0.799	0.602	1.597	1.204	2.396	1.805	3.195	2.407	3.993	**53°**
37¼	0.796	0.605	1.592	1.211	2.388	1.816	3.184	2.421	3.980	52¾
37½	0.793	0.609	1.587	1.218	2.380	1.826	3.173	2.435	3.967	52½
37¾	0.791	0.612	1.581	1.224	2.372	1.837	3.163	2.449	3.953	52¼
38°	0.788	0.616	1.576	1.231	2.364	1.847	3.152	2.463	3.940	**52°**
38¼	0.785	0.619	1.571	1.238	2.356	1.857	3.141	2.476	3.927	51¾
38½	0.783	0.623	1.565	1.245	2.348	1.868	3.130	2.490	3.913	51½
38¾	0.780	0.626	1.560	1.252	2.340	1.878	3.120	2.504	3.899	51¼
39°	0.777	0.629	1.554	1.259	2.331	1.888	3.109	2.517	3.886	**51°**
Bearing.	Dep. 1	Lat. 1	Dep. 2	Lat. 2	Dep. 3	Lat. 3	Dep. 4	Lat. 4	Dep. 5	Bearing.

Bearing.	5	6		7		8		9		Bearing.
	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	
26°	2.192	5.393	2.630	6.292	3.069	7.190	3.507	8.089	3.945	64°
26¼	2.211	5.381	2.654	6.278	3.096	7.175	3.538	8.072	3.981	63¾
26½	2.231	5.370	2.677	6.265	3.123	7.160	3.570	8.054	4.016	63½
26¾	2.250	5.358	2.701	6.251	3.151	7.144	3.601	8.037	4.051	63¼
27°	2.270	5.346	2.724	6.237	3.178	7.128	3.632	8.019	4.086	63°
27¼	2.289	5.334	2.747	6.223	3.205	7.112	3.663	8.001	4.121	62¾
27½	2.309	5.322	2.770	6.209	3.232	7.096	3.694	7.983	4.156	62½
27¾	2.328	5.310	2.794	6.195	3.259	7.080	3.725	7.965	4.190	62¼
28°	2.347	5.298	2.817	6.181	3.286	7.064	3.756	7.947	4.225	62°
28¼	2.367	5.285	2.840	6.166	3.313	7.047	3.787	7.928	4.260	61¾
28½	2.386	5.273	2.863	6.152	3.340	7.031	3.817	7.909	4.294	61½
28¾	2.405	5.260	2.886	6.137	3.367	7.014	3.848	7.891	4.329	61¼
29°	2.424	5.248	2.909	6.122	3.394	6.997	3.878	7.872	4.363	61°
29¼	2.443	5.235	2.932	6.107	3.420	6.980	3.909	7.852	4.398	60¾
29½	2.462	5.222	2.955	6.093	3.447	6.963	3.939	7.833	4.432	60½
29¾	2.481	5.209	2.977	6.077	3.474	6.946	3.970	7.814	4.466	60¼
30°	2.500	5.196	3.000	6.062	3.500	6.928	4.000	7.794	4.500	60°
30¼	2.519	5.183	3.023	6.047	3.526	6.911	4.030	7.775	4.534	59¾
30½	2.538	5.170	3.045	6.031	3.553	6.893	4.060	7.755	4.568	59½
30¾	2.556	5.156	3.068	6.016	3.579	6.875	4.090	7.735	4.602	59¼
31°	2.575	5.143	3.090	6.000	3.605	6.857	4.120	7.715	4.635	59°
31¼	2.594	5.129	3.113	5.984	3.631	6.839	4.150	7.694	4.669	58¾
31½	2.612	5.116	3.135	5.968	3.657	6.821	4.180	7.674	4.702	58½
31¾	2.631	5.102	3.157	5.952	3.683	6.803	4.210	7.653	4.736	58¼
32°	2.650	5.088	3.180	5.936	3.709	6.784	4.239	7.632	4.769	58°
32¼	2.668	5.074	3.202	5.920	3.735	6.766	4.269	7.612	4.802	57¾
32½	2.686	5.060	3.224	5.904	3.761	6.747	4.298	7.591	4.836	57½
32¾	2.705	5.046	3.246	5.887	3.787	6.728	4.328	7.569	4.869	57¼
33°	2.723	5.032	3.268	5.871	3.812	6.709	4.357	7.548	4.902	57°
33¼	2.741	5.018	3.290	5.854	3.838	6.690	4.386	7.527	4.935	56¾
33½	2.760	5.003	3.312	5.837	3.864	6.671	4.416	7.505	4.967	56½
33¾	2.778	4.989	3.333	5.820	3.889	6.652	4.445	7.483	5.000	56¼
34°	2.796	4.974	3.355	5.803	3.914	6.632	4.474	7.461	5.033	56°
34¼	2.814	4.960	3.377	5.786	3.940	6.613	4.502	7.439	5.065	55¾
34½	2.832	4.945	3.398	5.769	3.965	6.593	4.531	7.417	5.098	55½
34¾	2.850	4.930	3.420	5.752	3.990	6.573	4.560	7.395	5.130	55¼
35°	2.868	4.915	3.441	5.734	4.015	6.553	4.589	7.372	5.162	55°
35¼	2.886	4.900	3.463	5.716	4.040	6.533	4.617	7.350	5.194	54¾
35½	2.904	4.885	3.484	5.699	4.065	6.513	4.646	7.327	5.226	54½
35¾	2.921	4.869	3.505	5.681	4.090	6.493	4.674	7.304	5.258	54¼
36°	2.939	4.854	3.527	5.663	4.115	6.472	4.702	7.281	5.290	54°
36¼	2.957	4.839	3.548	5.645	4.139	6.452	4.730	7.258	5.322	53¾
36½	2.974	4.823	3.569	5.627	4.164	6.431	4.759	7.235	5.353	53½
36¾	2.992	4.808	3.590	5.609	4.188	6.410	4.787	7.211	5.385	53¼
37°	3.009	4.792	3.611	5.590	4.213	6.389	4.815	7.188	5.416	53°
37¼	3.026	4.776	3.632	5.572	4.237	6.368	4.842	7.164	5.448	52¾
37½	3.044	4.760	3.653	5.554	4.261	6.347	4.870	7.140	5.479	52½
37¾	3.061	4.744	3.673	5.535	4.286	6.326	4.898	7.116	5.510	52¼
38°	3.078	4.728	3.694	5.516	4.310	6.304	4.925	7.092	5.541	52°
38¼	3.095	4.712	3.715	5.497	4.334	6.283	4.953	7.068	5.572	51¾
38½	3.113	4.696	3.735	5.478	4.358	6.261	4.980	7.043	5.603	51½
38¾	3.130	4.679	3.756	5.459	4.381	6.239	5.007	7.019	5.633	51¼
39°	3.147	4.663	3.776	5.440	4.405	6.217	5.035	6.994	5.664	51°
	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	
Bearing.	5	6		7		8		9		Bearing.

Bearing.	1		2		3		4		5	Bearing.
	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	
39°	0.777	0.629	1.554	1.259	2.331	1.888	3.109	2.517	3.886	51°
39¼	0.774	0.633	1.549	1.265	2.323	1.898	3.098	2.531	3.872	50¾
39½	0.772	0.636	1.543	1.272	2.315	1.908	3.086	2.544	3.858	50½
39¾	0.769	0.639	1.538	1.279	2.307	1.918	3.075	2.558	3.844	50¼
40°	0.766	0.643	1.532	1.286	2.298	1.928	3.064	2.571	3.830	50°
40¼	0.763	0.646	1.526	1.292	2.290	1.938	3.053	2.584	3.816	49¾
40½	0.760	0.649	1.521	1.299	2.281	1.948	3.042	2.598	3.802	49½
40¾	0.758	0.653	1.515	1.306	2.273	1.958	3.030	2.611	3.788	49¼
41°	0.755	0.656	1.509	1.312	2.264	1.968	3.019	2.624	3.774	49°
41¼	0.752	0.659	1.504	1.319	2.256	1.978	3.007	2.637	3.759	48¾
41½	0.749	0.663	1.498	1.325	2.247	1.988	2.996	2.650	3.745	48½
41¾	0.746	0.666	1.492	1.332	2.238	1.998	2.984	2.664	3.730	48¼
42°	0.743	0.669	1.486	1.338	2.229	2.007	2.973	2.677	3.716	48°
42¼	0.740	0.672	1.480	1.345	2.221	2.017	2.961	2.689	3.701	47¾
42½	0.737	0.676	1.475	1.351	2.212	2.027	2.949	2.702	3.686	47½
42¾	0.734	0.679	1.469	1.358	2.203	2.036	2.937	2.715	3.672	47¼
43°	0.731	0.682	1.463	1.364	2.194	2.046	2.925	2.728	3.657	47°
43¼	0.728	0.685	1.457	1.370	2.185	2.056	2.913	2.741	3.642	46¾
43½	0.725	0.688	1.451	1.377	2.176	2.065	2.901	2.753	3.627	46½
43¾	0.722	0.692	1.445	1.383	2.167	2.075	2.889	2.766	3.612	46¼
44°	0.719	0.695	1.439	1.389	2.158	2.084	2.877	2.779	3.597	46°
44¼	0.716	0.698	1.433	1.396	2.149	2.093	2.865	2.791	3 582	45¾
44½	0.713	0.701	1.427	1.402	2.140	2.103	2.853	2.804	3.566	45½
44¾	0.710	0.704	1.420	1.408	2.131	2.112	2.841	2.816	3.551	45¼
45°	0.707	0.707	1.414	1.414	2.121	2.121	2.828	2.828	3.536	45°
Bearing.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Bearing.

Bearing.	5	6		7		8		9		Bearing.
	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	
39°	3.147	4.663	3.776	5.440	4.405	6.217	5.035	6.994	5.664	51°
39¼	3.164	4.646	3.796	5.421	4.429	6.195	5.062	6.970	5.694	50¾
39½	3.180	4.630	3.816	5.401	4.453	6.173	5.089	6.945	5.725	50½
39¾	3.197	4.613	3.837	5.382	4.476	6.151	5.116	6.920	5.755	50¼
40°	3.214	4.596	3.857	5.362	4.500	6.128	5.142	6.894	5.785	50°
40¼	3.231	4.579	3.877	5.343	4.523	6.106	5.169	6.869	5.815	49¾
40½	3.247	4.562	3.897	5.323	4.546	6.083	5.196	6.844	5.845	49½
40¾	3.264	4.545	3.917	5.303	4.569	6.061	5.222	6.818	5.875	49¼
41°	3.280	4.528	3.936	5.283	4.592	6.038	5.248	6.792	5.905	49°
41¼	3.297	4.511	3.956	5.263	4.615	6.015	5.275	6.767	5.934	48¾
41½	3.313	4.494	3.976	5.243	4.638	5.992	5.301	6.741	5.964	48½
41¾	3.329	4.476	3.995	5.222	4.661	5.968	5.327	6.715	5.993	48¼
42°	3.346	4.459	4.015	5.202	4.684	5.945	5.353	6.688	6.022	48°
42¼	3.362	4.441	4.034	5.182	4.707	5.922	5.379	6.662	6.051	47¾
42½	3.378	4.424	4.054	5.161	4.729	5.898	5.405	6.635	6.080	47½
42¾	3.394	4.406	4.073	5.140	4.752	5.875	5.430	6.609	6.109	47¼
43°	3.410	4.388	4.092	5.119	4.774	5.851	5.456	6.582	6.138	47°
43¼	3.426	4.370	4.111	5.099	4.796	5.827	5.481	6.555	6.167	46¾
43½	3.442	4.352	4.130	5.078	4.818	5.803	5.507	6.528	6.195	46½
43¾	3.458	4.334	4.149	5.057	4.841	5.779	5.532	6.501	6.224	46¼
44°	3.473	4.316	4.168	5.035	4.863	5.755	5.557	6.474	6.252	46°
44¼	3.489	4.298	4.187	5.014	4.885	5.730	5.582	6.447	6.280	45¾
44½	3.505	4.280	4.206	4.993	4.906	5.706	5.607	6.419	6.308	45½
44¾	3.520	4.261	4.224	4.971	4.928	5.681	5.632	6.392	6.336	45¼
45°	3.536	4.243	4.243	4.950	4.950	5.657	5.657	6.364	6.364	45°
Bearing.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Bearing.

SQUARES, CUBES, SQUARE AND CUBE ROOTS, CIRCUMFERENCES, AND AREAS.

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
1	1	1	1.0000	1.0000	1.000000000	3.1416	0.7854
2	4	8	1.4142	1.2599	.500000000	6.2832	3.1416
3	9	27	1.7321	1.4422	.333333333	9.4248	7.0686
4	16	64	2.0000	1.5874	.250000000	12.5664	12.5664
5	25	125	2.2361	1.7100	.200000000	15.7080	19.635
6	36	216	2.4495	1.8171	.166666667	18.850	28.274
7	49	343	2.6458	1.9129	.142857143	21.991	38.485
8	64	512	2.8284	2.0000	.125000000	25.133	50.266
9	81	729	3.0000	2.0801	.111111111	28.274	63.617
10	100	1,000	3.1623	2.1544	.100000000	31.416	78.540
11	121	1,331	3.3166	2.2240	.090909091	34.558	95.033
12	144	1,728	3.4641	2.2894	.083333333	37.699	113.10
13	169	2,197	3.6056	2.3513	.076923077	40.841	132.73
14	196	2,744	3.7417	2.4101	.071428571	43.982	153.94
15	225	3,375	3.8730	2.4662	.066666667	47.124	176.71
16	256	4,096	4.0000	2.5198	.062500000	50.265	201.06
17	289	4,913	4.1231	2.5713	.058823529	53.407	226.98
18	324	5,832	4.2426	2.6207	.055555556	56.549	254.47
19	361	6,859	4.3589	2.6684	.052631579	59.690	283.53
20	400	8,000	4.4721	2.7144	.050000000	62.832	314.16
21	441	9,261	4.5826	2.7589	.047619048	65.973	346.36
22	484	10,648	4.6904	2.8020	.045454545	69.115	380.13
23	529	12,167	4.7958	2.8439	.043478261	72.257	415.48
24	576	13,824	4.8990	2.8845	.041666667	75.398	452.39
25	625	15,625	5.0000	2.9240	.040000000	78.540	490.87
26	676	17,576	5.0990	2.9625	.038461538	81.681	530.93
27	729	19,683	5.1962	3.0000	.037037037	84.823	572.56
28	784	21,952	5.2915	3.0366	.035714286	87.965	615.75
29	841	24,389	5.3852	3.0723	.034482759	91.106	660.52
30	900	27,000	5.4772	3.1072	.033333333	94.248	706.86
31	961	29,791	5.5678	3.1414	.032258065	97.389	754.77
32	1,024	32,768	5.6569	3.1748	.031250000	100.53	804.25
33	1,089	35,937	5.7446	3.2075	.030303030	103.67	855.30
34	1,156	39,304	5.8310	3.2396	.029411765	106.81	907.92
35	1,225	42,875	5.9161	3.2717	.028571429	109.96	962.11
36	1,296	46,656	6.0000	3.3019	.027777778	113.10	1,017.88
37	1,369	50,653	6.0828	3.3322	.027027027	116.24	1,075.21
38	1,444	54,872	6.1644	3.3620	.026315789	119.38	1,134.11
39	1,521	59,319	6.2450	3.3912	.025641026	122.52	1,194.59
40	1,600	64,000	6.3246	3.4200	.025000000	125.66	1,256.64
41	1,681	68,921	6.4031	3.4482	.024390244	128.81	1,320.25
42	1,764	74,088	6.4807	3.4760	.023809524	131.95	1,385.44
43	1,849	79,507	6.5574	3.5034	.023255814	135.09	1,452.20
44	1,936	85,184	6.6332	3.5303	.022727273	138.23	1,520.53
45	2,025	91,125	6.7082	3.5569	.022222222	141.37	1,590.43
46	2,116	97,336	6.7823	3.5830	.021739130	144.51	1,661.90
47	2,209	103,823	6.8557	3.6088	.021276600	147.65	1,734.94
48	2,304	110,592	6.9282	3.6342	.020833333	150.80	1,809.56
49	2,401	117,649	7.0000	3.6593	.020408163	153.94	1,885.74
50	2,500	125,000	7.0711	3.6840	.020000000	157.08	1,963.50
51	2,601	132,651	7.1414	3.7084	.019607843	160.22	2,042.82
52	2,704	140,608	7.2111	3.7325	.019230769	163.36	2,123.72
53	2,809	148,877	7.2801	3.7563	.018867925	166.50	2,206.18
54	2,916	157,464	7.3485	3.7798	.018518519	169.65	2,290.22
55	3,025	166,375	7.4162	3.8030	.018181818	172.79	2,375.83

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
56	3,136	175,616	7.4833	3.8259	.017857143	175.93	2,463.01
57	3,249	185,193	7.5498	3.8485	.017543860	179.07	2,551.76
58	3,364	195,112	7.6158	3.8709	.017241379	182.21	2,642.08
59	3,481	205,379	7.6811	3.8930	.016949153	185.35	2,733.97
60	3,600	216,000	7.7460	3.9149	.016666667	188.50	2,827.43
61	3,721	226,981	7.8102	3.9365	.016393443	191.64	2,922.47
62	3,844	238,328	7.8740	3.9579	.016129032	194.78	3,019.07
63	3,969	250,047	7.9373	3.9791	.015873016	197.92	3,117.25
64	4,096	262,144	8.0000	4.0000	.015625000	201.06	3,216.99
65	4,225	274,625	8.0623	4.0207	.015384615	204.20	3,318.31
66	4,356	287,496	8.1240	4.0412	.015151515	207.34	3,421.19
67	4,489	300,763	8.1854	4.0615	.014925373	210.49	3,525.65
68	4,624	314,432	8.2462	4.0817	.014705882	213.63	3,631.68
69	4,761	328,509	8.3066	4.1016	.014492754	216.77	3,739.28
70	4,900	343,000	8.3666	4.1213	.014285714	219.91	3,848.45
71	5,041	357,911	8.4261	4.1408	.014084517	223.05	3,959.19
72	5,184	373,248	8.4853	4.1602	.013888889	226.19	4,071.50
73	5,329	389,017	8.5440	4.1793	.013698630	229.34	4,185.39
74	5,476	405,224	8.6023	4.1983	.013513514	232.48	4,300.84
75	5,625	421,875	8.6603	4.2172	.013333333	235.62	4,417.86
76	5,776	438,976	8.7178	4.2358	.013157895	238.76	4,536.46
77	5,929	456,533	8.7750	4.2543	.012987013	241.90	4,656.63
78	6,084	474,552	8.8318	4.2727	.012820513	245.04	4,778.36
79	6,241	493,039	8.8882	4.2908	.012658228	248.19	4,901.67
80	6,400	512,000	8.9443	4.3089	.012500000	251.33	5,026.55
81	6,561	531,441	9.0000	4.3267	.012345679	254.47	5,153.00
82	6,724	551,368	9.0554	4.3445	.012195122	257.61	5,281.02
83	6,889	571,787	9.1104	4.3621	.012048193	260.75	5,410.61
84	7,056	592,704	9.1652	4.3795	.011904762	263.89	5,541.77
85	7,225	614,125	9.2195	4.3968	.011764706	267.04	5,674.50
86	7,396	636,056	9.2736	4.4140	.011627907	270.18	5,808.80
87	7,569	658,503	9.3274	4.4310	.011494253	273.32	5,944.68
88	7,744	681,472	9.3808	4.4480	.011363636	276.46	6,082.12
89	7,921	704,969	9.4340	4.4647	.011235955	279.60	6,221.14
90	8,100	729,000	9.4868	4.4814	.011111111	282.74	6,361.73
91	8,281	753,571	9.5394	4.4979	.010989011	285.88	6,503.88
92	8,464	778,688	9.5917	4.5144	.010869565	289.03	6,647.61
93	8,649	804,357	9.6437	4.5307	.010752688	292.17	6,792.91
94	8,836	830,584	9.6954	4.5468	.010638298	295.31	6,939.78
95	9,025	857,375	9.7468	4.5629	.010526316	298.45	7,088.22
96	9,216	884,736	9.7980	4.5789	.410416667	301.59	7,238.23
97	9,409	912,673	9.8489	4.5947	.010309278	304.73	7,389.81
98	9,604	941,192	9.8995	4.6104	.010204082	307.88	7,542.96
99	9,801	970,299	9.9499	4.6261	.010101010	311.02	7,697.69
100	10,000	1,000,000	10.0000	4.6416	.010000000	314.16	7,853.98
101	10,201	1,030,301	10.0499	4.6570	.009900990	317.30	8,011.85
102	10,404	1,061,208	10.0995	4.6723	.009803922	320.44	8,171.28
103	10,609	1,092,727	10.1489	4.6875	.009708738	323.58	8,332.29
104	10,816	1,124,864	10.1980	4.7027	.009615385	326.73	8,494.87
105	11,025	1,157,625	10.2470	4.7177	.009523810	329.87	8,659.01
106	11,236	1,191,016	10.2956	4.7326	.009433962	333.01	8,824.73
107	11,449	1,225,043	10.3441	4.7475	.009345794	336.15	8,992.02
108	11,664	1,259,712	10.3923	4.7622	.009259259	339.29	9,160.88
109	11,881	1,295,029	10.4403	4.7769	.009174312	342.43	9,331.32
110	12,100	1,331,000	10.4881	4.7914	.009090909	345.58	9,503.32
111	12,321	1,367,631	10.5357	4.8059	.009009009	348.72	9,676.89
112	12,544	1,404,928	10.5830	4.8203	.008928571	351.86	9,852.03
113	12,769	1,442,897	10.6301	4.8346	.008849558	355.00	10,028.75
114	12,996	1,481,544	10.6771	4.8488	.008771930	358.14	10,207.03
115	13,225	1,520,875	10.7238	4.8629	.008695652	361.28	10,386.89
116	13,456	1,560,896	10.7703	4.8770	.008020690	364.42	10,568.32
117	13,689	1,601,613	10.8167	4.8910	.008547009	367.57	10,751.32
118	13,924	1,643,032	10.8628	4.9049	.008474576	370.71	10,935.88

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
119	14,161	1,685,159	10.9087	4.9187	.008403361	373.85	11,122.02
120	14,400	1,728,000	10.9545	4.9324	.008333333	376.99	11,309.73
121	14,641	1,771,561	11.0000	4.9461	.008264463	380.13	11,499.01
122	14,834	1,815,848	11.0454	4.9597	.008196721	383.27	11,689.87
123	15,129	1,860,867	11.0905	4.9732	.008130081	386.42	11,882.29
124	15,376	1,906,624	11.1355	4.9866	.008064516	389.56	12,076.28
125	15,625	1,953,125	11.1803	5.0000	.008000000	392.70	12,271.85
126	15,876	2,000,376	11.2250	5.0133	.007936508	395.84	12,468.98
127	16,129	2,048,383	11.2694	5.0265	.007874016	398.98	12,667.69
128	16,384	2,097,152	11.3137	5.0397	.007812500	402.12	12,867.96
129	16,641	2,146,689	11.3578	5.0528	.007751938	405.27	13,069.81
130	16,900	2,197,000	11.4018	5.0658	.007692308	408.41	13,273.23
131	17,161	2,248,091	11.4455	5.0788	.007633588	411.55	13,478.22
132	17,424	2,299,968	11.4891	5.0916	.007575758	414.69	13,684.78
133	17,689	2,352,637	11.5326	5.1045	.007518797	417.83	13,892.91
134	17,956	2,406,104	11.5758	5.1172	.007462687	420.97	14,102.61
135	18,225	2,460,375	11.6190	5.1299	.007407407	424.12	14,313.88
136	18,496	2,515,456	11.6619	5.1426	.007352941	427.26	14,526.72
137	18,769	2,571,353	11.7047	5.1551	.007299270	430.40	14,741.14
138	19,044	2,628,072	11.7473	5.1676	.007246377	433.54	14,957.12
139	19,321	2,685,619	11.7898	5.1801	.007194245	436.68	15,174.68
140	19,600	2,744,000	11.8322	5.1925	.007142857	439.82	15,393.80
141	19,881	2,803,221	11.8743	5.2048	.007092199	442.96	15,614.50
142	20,164	2,863,288	11.9164	5.2171	.007042254	446.11	15,836.77
143	20,449	2,924,207	11.9583	5.2293	.006993007	449.25	16,060.61
144	20,736	2,985,984	12.0000	5.2415	.006944444	452.39	16,286.02
145	21,025	3,048,625	12.0416	5.2536	.006896552	455.53	16,513.00
146	21,316	3,112,136	12.0830	5.2656	.006849315	458.67	16,741.55
147	21,609	3,176,523	12.1244	5.2776	.006802721	461.81	16,971.67
148	21,904	3,241,792	12.1655	5.2896	.006756757	464.96	17,203.36
149	22,201	3,307,949	12.2066	5.3015	.006711409	468.10	17,436.62
150	22,500	3,375,000	12.2474	5.3133	.006666667	471.24	17,671.46
151	22,801	3,442,951	12.2882	5.3251	.006622517	474.38	17,907.86
152	23,104	3,511,008	12.3288	5.3368	.006578947	477.52	18,145.84
153	23,409	3,581,577	12.3693	5.3485	.006535948	480.66	18,385.39
154	23,716	3,652,264	12.4097	5.3601	.006493506	483.81	18,626.50
155	24,025	3,723,875	12.4499	5.3717	.006451613	486.95	18,869.19
156	24,336	3,796,416	12.4900	5.3832	.006410256	490.09	19,113.45
157	24,649	3,869,893	12.5300	5.3947	.006369427	493.23	19,359.28
158	24,964	3,944,312	12.5698	5.4061	.006329114	496.37	19,606.68
159	25,281	4,019,679	12.6095	5.4175	.006289308	499.51	19,855.65
160	25,600	4,096,000	12.6491	5.4288	.006250000	502.65	20,106.19
161	25,921	4,173,281	12.6886	5.4401	.006211180	505.80	20,358.31
162	26,244	4,251,528	12.7279	5.4514	.006172840	508.94	20,611.99
163	26,569	4,330,747	12.7671	5.4626	.006134969	512.08	20,867.24
164	26,896	4,410,944	12.8062	5.4737	.006097561	515.22	21,124.07
165	27,225	4,492,125	12.8452	5.4848	.006060606	518.36	21,382.46
166	27,556	4,574,296	12.8841	5.4959	.006024096	521.50	21,642.43
167	27,889	4,657,463	12.9228	5.5069	.005988024	524.65	21,903.97
168	28,224	4,741,632	12.9615	5.5178	.005952381	527.79	22,167.08
169	28,561	4,826,809	13.0000	5.5288	.005917160	530.93	22,431.76
170	28,900	4,913,000	13.9384	5.5397	.005882353	534.07	22,698.01
171	29,241	5,000,211	13.0767	5.5505	.005847953	537.21	22,965.83
172	28,584	5,088,448	13.1149	5.5613	.005813953	540.35	23,235.22
173	29,929	5,177,717	13.1529	5.5721	.005780347	543.50	23,506.18
174	30,276	5,268,024	13.1909	5.5828	.005747126	546.64	23,778.71
175	30,625	5,359,375	13.2288	5.5934	.005714286	549.78	24,052.82
176	30,976	5,451,776	13.2665	5.6041	.005681818	552.92	24,328.49
177	31,329	5,545,233	13.3041	5.6147	.005649718	556.06	24,605.74
178	31,684	5,639,752	13.3417	5.6252	.005617978	559.20	24,884.56
179	32,041	5,735,339	13.3791	5.6357	.005586592	562.35	25,164.94
180	32,400	5,832,000	13.4164	5.6462	.005555556	565.49	25,446.90
181	32,761	5,929,741	13.4536	5.6567	.005524862	568.63	25,730.43

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
182	33,124	6,028,568	13.4907	5.6671	.005494505	571.77	26,015.53
183	33,489	6,128,487	13.5277	5.6774	.005464481	574.91	26,302.20
184	33,856	6,229,504	13.5647	5.6877	.005434783	578.05	26,590.44
185	34,225	6,331,625	13.6015	5.6980	.005405405	581.19	26,880.25
186	34,596	6,434,856	13.6382	5.7083	.005376344	584.34	27,171.63
187	34,969	6,539,203	13.6748	5.7185	.005347594	587.48	27,464.59
188	35,344	6,644,672	13.7113	5.7287	.005319149	590.62	27,759.11
189	35,721	6,751,269	13.7477	5.7388	.005291005	593.76	28,055.21
190	36,100	6,859,000	13.7840	5.7489	.005263158	596.90	28,352.87
191	36,481	6,967,871	13.8203	5.7590	.005235602	600.04	28,652.11
192	36,864	7,077,888	13.8564	5.7690	.005208333	603.19	28,952.92
193	37,249	7,189,017	13.8924	5.7790	.005181347	606.33	29,255.30
194	37,636	7,301,384	13.9284	5.7890	.005154639	609.47	29,559.25
195	38,025	7,414,875	13.9642	5.7989	.005128205	612.61	29,864.77
196	38,416	7,529,536	14.0000	5.8088	.005102041	615.75	30,171.86
197	38,809	7,645,373	14.0357	5.8186	.005076142	618.89	30,480.52
198	39,204	7,762,392	14.0712	5.8285	.005050505	622.04	30,790.75
199	39,601	7,880,599	14.1067	5.8383	.005025126	625.18	31,102.55
200	40,000	8,000,000	14.1421	5.8480	.005000000	628.32	31,415.93
201	40,401	8,120,601	14.1774	5.8578	.004975124	631.46	31,730.87
202	40,804	8,242,408	14.2127	5.8675	.004950495	634.60	32,047.39
203	41,209	8,365,427	14.2478	5.8771	.004926108	637.74	32,365.47
204	41,616	8,489,664	14.2829	5.8868	.004901961	640.88	32,685.13
205	42,025	8,615,125	14.3178	5.8964	.004878049	644.03	33,006.36
206	42,436	8,741,816	14.3527	5.9059	.004854369	647.17	33,329.16
207	42,849	8,869,743	14.3875	5.9155	.004830918	650.31	33,653.53
208	43,264	8,998,912	14.4222	5.9250	.004807692	653.45	33,979.47
209	43,681	9,129,329	14.4568	5.9345	.004784689	656.59	34,306.98
210	44,100	9,261,000	14.4914	5.9439	.004761905	659.73	34,636.06
211	44,521	9,393,931	14.5258	5.9533	.004739336	662.88	34,966.71
212	44,944	9,528,128	14.5602	5.9627	.004716981	666.02	35,298.94
213	45,369	9,663,597	14.5945	5.9721	.004694836	669.16	35,632.73
214	45,796	9,800,344	14.6287	5.9814	.004672897	672.30	35,968.09
215	46,225	9,938,375	14.6629	5.9907	.004651163	675.44	36,305.03
216	46,656	10,077,696	14.6969	6.0000	.004629630	678.58	36,643.54
217	47,089	10,218,313	14.7309	6.0092	.004608295	681.73	36,983.61
218	47,524	10,360,232	14.7648	6.0185	.004587156	684.87	37,325.26
219	47,961	10,503,459	14.7986	6.0277	.004566210	688.01	37,668.48
220	48,400	10,648,000	14.8324	6.0368	.004545455	691.15	38,013.27
221	48,841	10,793,861	14.8661	6.0459	.004524887	694.29	38,359.63
222	49,284	10,941,048	14.8997	6.0550	.004504505	697.43	38,707.56
223	49,729	11,089,567	14.9332	6.0641	.004484305	700.58	39,057.07
224	50,176	11,239,424	14.9666	6.0732	.004464286	703.72	39,408.14
225	50,625	11,390,625	15.0000	6.0822	.004444444	706.86	39,760.78
226	51,076	11,543,176	15.0333	6.0912	.004424779	710.00	40,115.00
227	51,529	11,697,083	15.0665	6.1002	.004405286	713.14	40,470.78
228	51,984	11,852,352	15.0997	6.1091	.004385965	716.28	40,828.14
229	52,441	12,008,989	15.1327	6.1180	.004366812	719.42	41,187.07
230	52,900	12,167,000	15.1658	6.1269	.004347826	722.57	41,547.56
231	53,361	12,326,391	15.1987	6.1358	.004329004	725.71	41,909.63
232	53,824	12,487,168	15.2315	6.1446	.004310345	728.85	42,273.27
233	54.289	12,649,337	15.2643	6.1534	.004291845	731.99	42,638.48
234	54,756	12,812,904	15.2971	6.1622	.004273504	735.13	43,005.26
235	55,225	12,977,875	15.3297	6.1710	.004255319	738.27	43,373.61
236	55,696	13,144,256	15.3623	6.1797	.004237288	741.42	43,743.54
237	56,169	13,312,053	15.3948	6.1885	.004219409	744.56	44,115.03
238	56,644	13,481,272	15.4272	6.1672	.004201681	747.70	44,488.09
239	57,121	13,651,919	15.4596	6.2058	.004184100	750.84	44,862.73
240	57,600	13,824,000	15.4919	6.2145	.004166667	753.98	45,238.93
241	58,081	13,997,521	15.5242	6.2231	.004149378	757.12	45,616.71
242	58,564	14,172,488	15.5563	6.2317	.004132231	760.27	45,996.06
243	59,049	14,348,907	15.5885	6.2403	.004115226	763.41	46,376.98
244	59,536	14,526,784	15.6205	6.2488	.004098361	766.55	46,759.47

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
245	60,025	14,706,125	15.6525	6.2573	.004081633	769.69	47,143.52
246	60,516	14,886,936	15.6844	6.2658	.004065041	772.83	47,529.16
247	61,009	15,069,223	15.7162	6.2743	.004048583	775.97	47,916.36
248	61,504	15,252,992	15.7480	6.2828	.004032258	779.11	48,305.13
249	62,001	15,438,249	15.7797	6.2912	.004016064	782.26	48,695.47
250	62,500	15,625,000	15.8114	6.2996	.004000000	785.40	49,087.39
251	63,001	15,813,251	15.8430	6.3080	.003984064	788.54	49,480.87
252	63,504	16,003,008	15.8745	6.3164	.003968254	791.68	49,875.92
253	64,009	16,194,277	15.9060	6.3247	.003952569	794.82	50,272.55
254	64,516	16,387,064	15.9374	6.3330	.003937008	797.96	50,670.75
255	65,025	16,581,375	15.9687	6.3413	.003921569	801.11	51,070.52
256	65,536	16,777,216	16.0000	6.3496	.003906250	804.25	51,471.85
257	66,049	16,974,593	16.0312	6.3579	.003891051	807.39	51,874.76
258	66,564	17,173,512	16.0624	6.3661	.003875969	810.53	52,279.24
259	67,081	17,373,979	16.0935	6.3743	.003861004	813.67	52,685.29
260	67,600	17,576,000	16.1245	6.3825	.003846154	816.81	53,092.92
261	68,121	17,779,581	16.1555	6.3907	.003831418	819.96	53,502.11
262	68,644	17,984,728	16.1864	6.3988	.003816794	823.10	53,912.87
263	69,169	18,191,447	16.2173	6.4070	.003802281	826.24	54,325.21
264	69,696	18,399,744	16.2481	6.4151	.003787879	829.38	54,739.11
265	70,225	18,609,625	16.2788	6.4232	.003773585	832.52	55,154.59
266	70,756	18,821,096	16.3095	6.4312	.003759398	835.66	55,571.63
267	71,289	19,034,163	16.3401	6.4393	.003745318	838.81	55,990.25
268	71,824	19,248,832	16.3707	6.4473	.003731343	841.95	56,410.44
269	72,361	19,465,109	16.4012	6.4553	.003717472	845.09	56,832.20
270	72,900	19,683,000	16.4317	6.4633	.003703704	848.23	57,255.53
271	73,441	19,902,511	16.4621	6.4713	.003690037	851.37	57,680.43
272	73,984	20,123,643	16.4924	6.4792	.003676471	854.51	58,106.90
273	74,529	20,346,417	16.5227	6.4872	.003663004	857.65	58,534.94
274	75,076	20,570,824	16.5529	6.4951	.003649635	860.80	58,964.55
275	75,625	20,796,875	16.5831	6.5030	.003636364	863.94	59,395.74
276	76,176	21,024,576	16.6132	6.5108	.003623188	867.08	59,828.49
277	76,729	21,253,933	16.6433	6.5187	.003610108	870.22	60,262.82
278	77,284	21,484,952	16.6783	6.5265	.003597122	873.36	60,698.71
279	77,841	21,717,639	16.7033	6.5343	.003584229	876.50	61,136.18
280	78,400	21,952,000	16.7332	6.5421	.003571429	879.65	61,575.22
281	78,961	22,188,041	16.7631	6.5499	.003558719	882.79	62,015.82
282	79,524	22,425,768	16.7929	6.5577	.003546099	885.93	62,458.00
283	80,089	22,665,187	16.8226	6.5654	.003533569	889.07	62,901.75
284	80,656	22,906,304	16.8523	6.5731	.003522127	892.21	63,347.07
285	81,225	23,149,125	16.8819	6.5808	.003508772	895.35	63,793.97
286	81,796	23,393,656	16.9115	6.5885	.003496503	898.50	64,242.43
287	82,369	23,639,903	16.9411	6.5962	.003484321	901.64	64,692.46
288	82,944	23,887,872	16.9706	6.6039	.003472222	904.78	65,144.07
289	83,521	24,137,569	17.0000	6.6115	.003460208	907.92	65,597.24
290	84,100	24,389,000	17.0294	6.6191	.003448276	911.06	66,051.99
291	84,681	24,642,171	17.0587	6.6267	.003436426	914.20	66,508.30
292	85,264	24,897,088	17.0880	6.6343	.003424658	917.35	66,966.19
293	85,849	25,153,757	17.1172	6.6419	.003412969	920.49	67,425.65
294	86,436	25,412,184	17.1464	6.6494	.003401361	923.63	67,886.68
295	87,025	25,672,375	17.1756	6.6569	.003389831	926.77	68,349.28
296	87,616	25,934,836	17.2047	6.6644	.003378378	929.91	68,813.45
297	88,209	26,198,073	17.2337	6.6719	.003367003	933.05	69,279.19
298	88,804	26,463,592	17.2627	6.6794	.003355705	936.19	69,746.50
299	89,401	26,730,899	17.2916	6.6869	.003344482	939.34	70,215.38
300	90,000	27,000,000	17.3205	6.6943	.003333333	942.48	70,685.83
301	90,601	27,270,901	17.3494	6.7018	.003322259	945.62	71,157.86
302	91,204	27,543,608	17.3781	6.7092	.003311258	948.76	71,631.45
303	91,809	27,818,127	17.4069	6.7166	.003301330	951.90	72,106.62
304	92,416	28,094,464	17.4356	6.7240	.003289474	955.04	72,583.36
305	93,025	28,372,625	17.4642	6.7313	.003278689	958.19	73,061.66
306	93,636	28,652,616	17.4929	6.7387	.003267974	961.33	73,541.54
307	94,249	28,934,443	17.5214	6.7460	.003257329	964.47	74,022.99

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
308	94,864	29,218,112	17.5499	6.7533	.003246753	967.61	74,506.01
309	95,481	29,503,629	17.5784	6.7606	.003236246	970.75	74,990.60
310	96,100	29,791,000	17.6068	6.7679	.003225806	973.89	75,476.76
311	96,721	30,080,231	17.6352	6.7752	.003215434	977.04	75,964.50
312	97,344	30,371,328	17.6635	6.7824	.003205128	980.18	76,453.80
313	97,969	30,664,297	17.6918	6.7897	.003194888	983.32	76,944.67
314	98,596	30,959,144	17.7200	6.7969	.003184713	986.46	77,437.12
315	99,225	31,255,875	17.7482	6.8041	.003174603	989.60	77,931.13
316	99,856	31,554,496	17.7764	6.8113	.003164557	992.74	78,426.72
317	100,489	31,855,013	17.8045	6.8185	.003154574	995.88	78,923.88
318	101,124	32,157,432	17.8326	6.8256	.003144654	999.03	79,422.60
319	101,761	32,461,759	17.8606	6.8328	.003134796	1,002.17	79,922.90
320	102,400	32,768,000	17.8885	6.8399	.003125000	1,005.31	80,424.77
321	103,041	33,076,161	17.9165	6.8470	.003115265	1,008.45	80,928.21
322	103,684	33,386,248	17.9444	6.8541	.003105590	1,011.59	81,433.22
323	104,329	33,698,267	17.9722	6.8612	.003095975	1,014.73	81,939.80
324	104,976	34,012,224	18.0000	6.8683	.003086420	1,017.88	82,447.96
325	105,625	34,328,125	18.0278	6.8753	.003076923	1,021.02	82,957.68
326	106,276	34,645,976	18.0555	6.8824	.003067485	1,024.16	83,468.98
327	106,929	34,965,783	18.0831	6.8894	.003058104	1,027.30	83,981.84
328	107,584	35,287,552	18.1108	6.8964	.003048780	1,030.44	84,496.28
329	108,241	35,611,289	18.1384	6.9034	.003039514	1,033.58	85,012.28
330	108,900	35,937,000	18.1659	6.9104	.003030303	1,036.73	85,529.86
331	109,561	36,264,691	18.1934	6.9174	.003021148	1,039.87	86,049.01
332	110,224	36,594,368	18.2209	6.9244	.003012048	1,043.01	86,569.73
333	110,889	36,926,037	18.2483	6.9313	.003003003	1,046.15	87,092.02
334	111,556	37,259,704	18.2757	6.9382	.002994012	1,049.29	87,615.88
335	112,225	37,595,375	18.3030	6.9451	.002985075	1,052.43	88,141.31
336	112,896	37,933,056	18.3303	6.9521	.002976190	1,055.58	88,668.31
337	113,569	38,272,753	18.3576	6.9589	.002967359	1,058.72	89,196.88
338	114,244	38,614,472	18.3848	6.9658	.002958580	1,061.86	89,727.03
339	114,921	38,958,219	18.4120	6.9727	.002949853	1,065.00	90,258.74
340	115,600	39,304,000	18.4391	6.9795	.002941176	1,068.14	90,792.03
341	116,281	39,651,821	18.4662	6.9864	.002932551	1,071.28	91,326.88
342	116,964	40,001,688	18.4932	6.9932	.002923977	1,074.42	91,863.31
343	117,649	40,353,607	18.5203	7.0000	.002915452	1,077.57	92,401.31
344	118,336	40,707,584	18.5472	7.0068	.002906977	1,080.71	92,940.88
345	119,025	41,063,625	18.5742	7.0136	.002898551	1,083.85	93,482.02
346	119,716	41,421,736	18.6011	7.0203	.002890173	1,086.99	94,024.73
347	120,409	41,781,923	18.6279	7.0271	.002881844	1,090.13	94,569.01
348	121,104	42,144,192	18.6548	7.0338	.002873563	1,093.27	95,114.86
349	121,801	42,508,549	18.6815	7.0406	.002865330	1,096.42	95,662.28
350	122,500	42,875,000	18.7083	7.0473	.002857143	1,099.56	96,211.28
351	123,201	43,243,551	18.7350	7.0540	.002849003	1,102.70	96,761.84
352	123,904	43,614,208	18.7617	7.0607	.002840909	1,105.84	97,313.97
353	124,609	43,986,977	18.7883	7.0674	.002832861	1,108.98	97,867.68
354	125,316	44,361,864	18.8149	7.0740	.002824859	1,112.12	98,422.96
355	126,025	44,738,875	18.8414	7.0807	.002816901	1,115.27	98,979.80
356	126,736	45,118,016	18.8680	7.0873	.002808989	1,118.41	99,538.22
357	127,449	45,499,293	18.8944	7.0940	.002801120	1,121.55	100,098.21
358	128,164	45,882,712	18.9209	7.1006	.002793296	1,124.69	100,659.77
359	128,881	46,268,279	18.9473	7.1072	.002785515	1,127.83	101,222.90
360	129,600	46,656,000	18.9737	7.1138	.002777778	1,130.97	101,787.60
361	130,321	47,045,881	19.0000	7.1204	.002770083	1,134.11	102,353.87
362	131,044	47,437,928	19.0263	7.1269	.002762431	1,137.26	102,921.72
363	131,769	47,832,147	19.0526	7.1335	.002754821	1,140.40	103,491.13
364	132,496	48,228,544	19.0788	7.1400	.002747253	1,143.54	104,062.12
365	133,225	48,627,125	19.1050	7.1466	.002739726	1,146.68	104,634.67
366	133,956	49,027,896	19.1311	7.1531	.002732240	1,149.82	105,208.80
367	134,689	49,430,863	19.1572	7.1596	.002724796	1,152.96	105,784.49
368	135,424	49,836,032	19.1833	7.1661	.002717391	1,156.11	106,361.76
369	136,161	50,243,409	19.2094	7.1726	.002710027	1,159.25	106,940.60
370	136,900	50,653,000	19.2354	7.1791	.002702703	1,162.39	107,521.01

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
371	137,641	51,064,811	19.2614	7.1855	.002695418	1,165.53	108,102.99
372	138,384	51,478,848	19.2873	7.1920	.002688172	1,168.67	108,686.54
373	139,129	51,895,117	19.3132	7.1984	.002680965	1,171.81	109,271.66
374	139,876	52,313,624	19.3391	7.2048	.002673797	1,174.96	109,858.35
375	140,625	52,734,375	19.3649	7.2112	.002666667	1,178.10	110,446.62
376	141,376	53,157,376	19.3907	7.2177	.002659574	1,181.24	111,036.45
377	142,129	53,582,633	19.4165	7.2240	.002652520	1,184.38	111,627.86
378	142,884	54,010,152	19.4422	7.2304	.002645503	1,187.52	112,220.83
379	143,641	54,439,939	19.4679	7.2368	.002638521	1,190.66	112,815.38
380	144,400	54,872,000	19.4936	7.2432	.002631579	1,193.81	113,411.49
381	145,161	55,306,341	19.5192	7.2495	.002624672	1,196.95	114,009.18
382	145,924	55,742,968	19.5448	7.2558	.002617801	1,200.09	114,608.44
383	146,689	56,181,887	19.5704	7.2622	.002610966	1,203.23	115,209.27
384	147,456	56,623,104	19.5959	7.2685	.002604167	1,206.37	115,811.67
385	148,225	57,066,625	19.6214	7.2748	.002597403	1,209.51	116,415.64
386	148,996	57,512,456	19.6469	7.2811	.002590674	1,212.65	117,021.18
387	149,769	57,960,603	19.6723	7.2874	.002583979	1,215.80	117,628.30
388	150,544	58,411,072	19.6977	7.2936	.002577320	1,218.94	118,236.98
389	151,321	58,863,869	19.7231	7.2999	.002570694	1,222.08	118,847.24
390	152,100	59,319,000	19.7484	7.3061	.002564103	1.225.22	119,459.06
391	152,881	59,776,471	19.7737	7.3124	.002557545	1,228.36	120,072.46
392	153,664	60,236,288	19.7990	7.3186	.002551020	1,231.50	120,687.42
393	154,449	60,698,457	19.8242	7.3248	.002544529	1,234.65	121,303.96
394	155,236	61,162,984	19.8494	7.3310	.002538071	1,237.79	121,922.07
395	156,025	61,629,875	19.8746	7.3372	.002531646	1,240.93	122,541.75
396	156,816	62,099,136	19.8997	7.3434	.002525253	1,244.07	123,163.00
397	157,609	62,570,773	19.9249	7.3496	.002518892	1,247.21	123,785.82
398	158,404	63,044,792	19.9499	7.3558	.002512563	1,250.35	124,410.21
399	159,201	63,521,199	19.9750	7.3619	.002506266	1,253.50	125,036.17
400	160,000	64,000,000	20.0000	7.3681	.002500000	1,256.64	125,663.71
401	160,801	64,481,201	20.0250	7.3742	.002493766	1,259.78	126,292.81
402	161,604	64,964,808	20.0499	7.3803	.002487562	1,262.92	126,923.48
403	162,409	65,450,827	20.0749	7.3864	.002481390	1,266.06	127,555.73
404	163,216	65,939,264	20.0998	7.3925	.002475248	1,269.20	128,189.55
405	164,025	66,430,125	20.1246	7.3986	.002469136	1,272.35	128,824.93
406	164,836	66,923,416	20.1494	7.4047	.002463054	1,275.49	129,461.89
407	165,649	67,419,143	20.1742	7.4108	.002457002	1,278.63	130,100.42
408	166,464	67,917,312	20.1990	7.4169	.002450980	1,281.77	130,740.52
409	167,281	68,417,929	20.2237	7.4229	.002444988	1,284.91	131,382.19
410	168,100	68,921,000	20.2485	7.4290	.002439024	1,288.05	132,025.43
411	168,921	69,426,531	20.2731	7.4350	.002433090	1,291.19	132,670.24
412	169,744	69,934,528	20.2978	7.4410	.002427184	1,294.34	133,316.63
413	170,569	70,444,997	20.3224	7.4470	.002421308	1,297.48	133,964.58
414	171,396	70,957,944	20.3470	7.4530	.002415459	1,300.62	134,614.10
415	172,225	71,473,375	20.3715	7.4590	.002409639	1,303.76	135,265.20
416	173,056	71,991,296	20.3961	7.4650	.002406846	1,306.90	135,917.86
417	173,889	72,511,713	20.4206	7.4710	.002398082	1,310.04	136,572.10
418	174,724	73,034,632	20.4450	7.4770	.002392344	1,313.19	137,227.91
419	175,561	73,560,059	20.4695	7.4829	.002386635	1,316.33	137,885.29
420	176,400	74,088,000	20.4939	7.4889	.002380952	1,319.47	138,544.24
421	177,241	74,618,461	20.5183	7.4948	.002375297	1,322.61	139,204.76
422	178,084	75,151,448	20.5426	7.5007	.002369668	1,325.75	139,866.85
423	178,929	75,686,967	20.5670	7.5067	.002364066	1,328.89	140,530.51
424	179,776	76,225,024	20.5913	7.5126	.002358491	1,332.04	141,195.74
425	180,625	76,765,625	20.6155	7.5185	.002352941	1,335.18	141,862.54
426	181,476	77,308,776	20.6398	7.5244	.002347418	1,338.32	142,530.92
427	182,329	77,854,483	20.6640	7.5302	.002341920	1,341.46	143,200.86
428	183,184	78,402,752	20.6882	7.5361	.002336449	1,344.60	143,872.38
429	184,041	78,953,589	20.7123	7.5420	.002331002	1,347.74	144,545.46
430	184,900	79,507,000	20.7364	7.5478	.002325581	1,350.88	145,220.12
431	185,761	80,062,991	20.7605	7.5537	.002320186	1,354.03	145,896.35
432	186,624	80,621,568	20.7846	7.5595	.002314815	1,357.17	146,574.15
433	187,489	81,182,737	20.8087	7.5654	.002309469	1,360.31	147,253.52

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
434	188,356	81,746,504	20.8327	7.5712	.002304147	1,363.45	147,934.46
435	189,225	82,312,875	20.8567	7.5770	.002298851	1,366.59	148,616.97
436	190,096	82,881,856	20.8806	7.5828	.002293578	1,369.73	149,301.05
437	190,969	83,453,453	20.9045	7.5886	.002288330	1,372.88	149,986.70
438	191,844	84,027,672	20.9284	7.5944	.002283105	1,376.02	150,673.93
439	192,721	84,604,519	20.9523	7.6001	.002277904	1,379.16	151,362.72
440	193,600	85,184,000	20.9762	7.6059	.002272727	1,382.30	152,053.08
441	194,481	85,766,121	21.0000	7.6117	.002267574	1,385.44	152,745.02
442	195,364	86,350,888	21.0238	7.6174	.002262443	1,388.58	153,438.53
443	196,249	86,938,307	21.0476	7.6232	.002257336	1,391.73	154,133.60
444	197,136	87,528,384	21.0713	7.6289	.002252252	1,394.87	154,830.25
445	198,025	88,121,125	21.0950	7.6346	.002247191	1,398.01	155,528.47
446	198,916	88,716,536	21.1187	7.6403	.002242152	1,401.15	156,228.26
447	199,809	89,314,623	21.1424	7.6460	.002237136	1,404.29	156,929.62
448	200,704	89,915,392	21.1660	7.6517	.002232143	1,407.43	157,632.55
449	201,601	90,518,849	21.1896	7.6574	.002227171	1,410.58	158,337.06
450	202,500	91,125,000	21.2132	7.6631	.002222222	1,413.72	159,043.13
451	203,401	91,733,851	21.2368	7.6688	.002217295	1,416.86	159,750.77
452	204,304	92,345,408	21.2603	7.6744	.002212389	1,420.00	160,459.99
453	205,209	92,959,677	21.2838	7.6801	.002207506	1,423.14	161,170.77
454	206,116	93,576,664	21.3073	7.6857	.002202643	1,426.28	161,883.13
455	207,025	94,196,375	21.3307	7.6914	.002197802	1,429.42	162,597.05
456	207,936	94,818,816	21.3542	7.6970	.002192982	1,432.57	163,312.55
457	208,849	95,443,993	21.3776	7.7026	.002188184	1,435.71	164,029.62
458	209,764	96,071,912	21.4009	7.7082	.002183406	1,438.85	164,748.26
459	210,681	96,702,579	21.4243	7.7188	.002178649	1,441.99	165,468.47
460	211,600	97,336,000	21.4476	7.7194	.002173913	1,445.13	166,190.25
461	212,521	97,972,181	21.4709	7.7250	.002169197	1,448.27	166,913.60
462	213,444	98,611,128	21.4942	7.7306	.002164502	1,451.42	167,638.53
463	214,369	99,252,847	21.5174	7.7362	.002159827	1,454.56	168,365.02
464	215,296	99,897,344	21.5407	7.7418	.002155172	1,457.70	169,093.08
465	216,225	100,544,625	21.5639	7.7473	.002150538	1,460.84	169,822.72
466	217,156	101,194,696	21.5870	7.7529	.002145923	1,463.98	170,553.92
467	218,089	101,847,563	21.6102	7.7584	.002141328	1,467.12	171,286.70
468	219,024	102,503,232	21.6333	7.7639	.002136752	1,470.27	172,021.05
469	219,961	103,161,709	21.6564	7.7695	.002132196	1,473.41	172,756.97
470	220,900	103,823,000	21.6795	7.7750	.002127660	1,476.55	173,494.45
471	221,841	104,487,111	21.7025	7.7805	.002123142	1,479.69	174,233.51
472	222,784	105,154,048	21.7256	7.7860	.002118644	1,482.83	174,974.14
473	223,729	105,823,817	21.7486	7.7915	.002114165	1,485.97	175,716.35
474	224,676	106,496,424	21.7715	7.7970	.002109705	1,489.11	176,460.12
475	225,625	107,171,875	21.7945	7.8025	.002105263	1,492.26	177,205.46
476	226,576	107,850,176	21.8174	7.8079	.002100840	1,495.40	177,952.37
477	227,529	108,531,333	21.8403	7.8134	.002096486	1,498.54	178,700.86
478	228,484	109,215,352	21.8632	7.8188	.002092050	1,501.68	179,450.91
479	229,441	109,902,239	21.8861	7.8243	.002087683	1,504.82	180,202.54
480	230,400	110,592,000	21.9089	7.8297	.002083333	1,507.96	180,955.74
481	231,361	111,284,641	21.9317	7.8352	.002079002	1,511.11	181,710.50
482	232,324	111,980,168	21.9545	7.8406	.002074689	1,514.25	182,466.84
483	233,289	112,678,587	21.9775	7.8460	.002070393	1.517.39	183,224.75
484	234,256	113,379,904	22.0000	7.8514	.002066116	1,520.53	183,984.23
485	235,225	114,084,125	22.0227	7.8568	.002061856	1,523.67	184,745.28
486	236,196	114,791,256	22.0454	7.8622	.002057613	1,526.81	185,507.90
487	237,169	115,501,303	22.0681	7.8676	.002053388	1,529.96	186,272.10
488	238,144	116,214,272	22.0907	7.8730	.002049180	1,533.10	187,037.86
489	239,121	116,930,169	22.1133	7.8784	.002044990	1,536.24	187,805.19
490	240,100	117,649,000	22.1359	7.8837	.002040816	1,539.38	188,574.10
491	241,081	118,370,771	22.1585	7.8891	.002036660	1,542.52	189,344.57
492	242,064	119,095,488	22.1811	7.8944	.002032520	1,545.66	190,116.62
493	243,049	119,823,157	22.2036	7.8998	.002028398	1,548.81	190,890.24
494	244,036	120,553,784	22.2261	7.9051	.002024291	1,551.95	191,665.43
495	245,025	121,287,375	22.2486	7.9105	.002020292	1,555.09	192,442.18
496	246,016	122,023,936	22.2711	7.9158	.002016129	1,558.23	193,220.51

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
497	247,009	122,763,473	22.2935	7.9211	.002012072	1,561.37	194,000.41
498	248,004	123,505,992	22.3159	7.9264	.002008032	1,564.51	194,781.89
499	249,001	124,251,499	22.3383	7.9317	.002004008	1,567.65	195,564.93
500	250,000	125,000,000	22.3607	7.9370	.002000000	1,570.80	196,349.54
501	251,001	125,751,501	22.3830	7.9423	.001996008	1,573.94	197,135.72
502	252,004	126,506,008	22.4054	7.9476	.001992032	1,577.08	197,923.48
503	253,009	127,263,527	22.4277	7.9528	.001988072	1,580.22	198,712.80
504	254,016	128,024,064	22.4499	7.9581	.001984127	1,583.36	199,503.70
505	255,025	128,787,625	22.4722	7.9634	.001980198	1,586.50	200,296.17
506	256,036	129,554,216	22.4944	7.9686	.001976285	1,589.65	201,090.20
507	257,049	130,323,843	22.5167	7.9739	.001972387	1,592.79	201,885.81
508	258,064	131,096,512	22.5389	7.9791	.001968504	1,595.93	202,682.99
509	259,081	131,872,229	22.5610	7.9843	.001964637	1,599.07	203,481.74
510	260,100	132,651,000	22.5832	7.9895	.001960785	1,602.21	204,282.06
511	261,121	133,432,831	22.6053	7.9948	.001956947	1,605.35	205,083.95
512	262,144	134,217,728	22.6274	8.0000	.001953125	1,608.50	205,887.42
513	263,169	135,005,697	22.6495	8.0052	.001949318	1,611.64	206,692.45
514	264,196	135,796,744	22.6716	8.0104	.001945525	1,614.78	207,499.05
515	265,225	136,590,875	22.6936	8.0156	.001941748	1,617.92	208,307.23
516	266,256	137,388,096	22.7156	8.0208	.001937984	1,621.06	209,116.97
517	267,289	138,188,413	22.7376	8.0260	.001934236	1,624.20	209,928.29
518	268,324	138,991,832	22.7596	8.0311	.001930502	1,627.34	210,741.18
519	269,361	139,798,359	22.7816	8.0363	.001926782	1,630.49	211,555.63
520	270,400	140,608,000	22.8035	8.0415	.001923077	1,633.63	212,371.66
521	271,411	141,420,761	22.8254	8.0466	.001919386	1,636.77	213,189.26
522	272,484	142,236,648	22.8473	8.0517	.001915709	1,639.91	214,008.43
523	273,529	143,055,667	22.8692	8.0569	.001912046	1,643.05	214,829.17
524	274,576	143,877,824	22.8910	8.0620	.001908397	1,646.19	215,651.49
525	275,625	144,703,125	22.9129	8.0671	.001904762	1,649.34	216,475.37
526	276,676	145,531,576	22.9347	8.0723	.001901141	1,652.48	217,300.82
527	277,729	146,363,183	22.9565	8.0774	.001897533	1,655.62	218,127.85
528	278,784	147,197,952	22.9783	8.0825	.001893939	1,658.76	218,956.44
529	279,841	148,035,889	23.0000	8.0876	.001890359	1,661.90	219,786.61
530	280,900	148,877,001	23.0217	8.0927	.001886792	1,665.04	220,618.34
531	281,961	149,721,291	23.0434	8.0978	.001883239	1,668.19	221,451.65
532	283,024	150,568,768	23.0651	8.1028	.001879699	1,671.33	222,286.53
533	284,089	151,419,437	23.0868	8.1079	.001876173	1,674.47	223,122.98
534	285,156	152,273,304	23.1084	8.1130	.001872659	1,677.61	223,961.00
535	286,225	153,130,375	23.1301	8.1180	.001869159	1,680.75	224,800.59
536	287,296	153,990,656	23.1517	8.1231	.001865672	1,683.89	225,641.75
537	288,369	154,854,153	23.1733	8.1281	.001862197	1,687.04	226,484.48
538	289,444	155,720,872	23.1948	8.1332	.001858736	1,690.18	227,328.79
539	290,521	156,590,819	23.2164	8.1382	.001855288	1,693.32	228,174.66
540	291,600	157,464,000	23.2379	8.1433	.001851852	1,696.46	229,022.10
541	292,681	158,340,421	23.2594	8.1483	.001848429	1,699.60	229,871.12
542	293,764	159,220,088	23.2809	8.1533	.001845018	1,702.74	230,721.71
543	294,849	160,103,007	23.3024	8.1583	.001841621	1,705.88	231,573.86
544	295,936	160,989,184	23.3238	8.1633	.001838235	1,709.03	232,427.59
545	297,025	161,878,625	23.3452	8.1683	.001834862	1,712.17	233,282.89
546	298,116	162,771,336	23.3666	8.1733	.001831502	1,715.31	234,139.76
547	299,209	163,667,323	23.3880	8.1783	.001828154	1,718.45	234,998.20
548	300,304	164,566,592	23.4094	8.1833	.001824818	1,721.59	235,858.21
549	301,401	165,469,149	23.4307	8.1882	.001821494	1,724.73	236,719.79
550	302,500	166,375,000	23.4521	8.1932	.001818182	1,727.88	237,582.94
551	303,601	167,284,151	23.4734	8.1982	.001814882	1,731.02	238,447.67
552	304,704	168,196,608	23.4947	8.2031	.001811594	1,734.16	239,313.96
553	305,809	169,112,377	23.5160	8.2081	.001808318	1,737.30	240,181.83
554	306,916	170,031,464	23.5372	8.2130	.001805054	1,740.44	241,051.26
555	308,025	170,953,875	23.5584	8.2180	.001801802	1,743.58	241,922.27
556	309,136	171,879,616	23.5797	8.2229	.001798561	1,746.73	242,794.85
557	310,249	172,808,693	23.6008	8.2278	.001795332	1,749.87	243,668.99
558	311,364	173,741,112	23.6220	8.2327	.001792115	1,753.01	244,544.71
559	312,481	174,676,879	23.6432	8.2377	.001788909	1,756.15	245,422.00

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
560	313,600	175,616,000	23.6643	8.2426	.001785714	1,759.29	246,300.86
561	314,721	176,558,481	23.6854	8.2475	.001782531	1,762.43	247,181.30
562	315,844	177,504,328	23.7065	8.2524	.001779359	1,765.58	248,063.30
563	316,969	178,453,547	23.7276	8.2573	.001776199	1,768.72	248,946.87
564	318,096	179,406,144	23.7487	8.2621	.001773050	1,771.86	249,832.01
565	319,225	180,362,125	23.7697	8.2670	.001769912	1,775.00	250,718.73
566	320,356	181,321,496	23.7908	8.2719	.001766784	1,778.14	251,607.01
567	321,489	182,284,263	23.8118	8.2768	.001763668	1,781.28	252,496.87
568	322,624	183,250,432	23.8328	8.2816	.001760563	1,784.42	253,388.30
569	323,761	184,220,009	23.8537	8.2865	.001757469	1,787.57	254,281.29
570	324,900	185,193,000	23.8747	8.2913	.001754386	1,790.71	255,175.86
571	326,041	186,169,411	23.8956	8.2962	.001751313	1,793.85	256,072.00
572	327,184	187,149,248	23.9165	8.3010	.001748252	1,796.99	256,969.71
573	328,329	188,132,517	23.9374	8.3059	.001745201	1,800.13	257,868.99
574	329,476	189,119,224	23.9583	8.3107	.001742164	1,803.27	258,769.85
575	330,625	190,109,375	23.9792	8.3155	.001739130	1,806.42	259,672.27
576	331,776	191,102,976	24.0000	8.3203	.001736111	1,809.56	260,576.26
577	332,929	192,100,033	24.0208	8.3251	.001733102	1,812.70	261,481.83
578	334,084	193,100,552	24.0416	8.3300	.001730104	1,815.84	262,388.96
579	335,241	194,104,539	24.0624	8.3348	.001727116	1,818.98	263,297.67
580	336,400	195,112,000	24.0832	8.3396	.001724138	1,822.12	264,207.94
581	337,561	196,122,941	24.1039	8.3443	.001721170	1,825.27	265,119.79
582	338,724	197,137,368	24.1247	8.3491	.001718213	1,828.41	266,033.21
583	339,889	198,155,287	24.1454	8.3539	.001715266	1,831.55	266,948.20
584	341,056	199,176,704	24.1661	8.3587	.001712329	1,834.69	267,864.76
585	342,225	200,201,625	24.1868	8.3634	.001709402	1,837.83	268,782.89
586	343,396	201,230,056	24.2074	8.3682	.001706485	1,840.97	269,702.59
587	344,569	202,262,003	24.2281	8.3730	.001703578	1,844.11	270,623.86
588	345,744	203,297,472	24.2487	8.3777	.001700680	1,847.26	271,546.70
589	346,921	204,336,469	24.2693	8.3825	.001697793	1,850.40	272,471.12
590	348,100	205,379,000	24.2899	8.3872	.001694915	1,853.54	273,397.10
591	349,281	206,425,071	24.3105	8.3919	.001692047	1,856.68	274,324.66
592	350,464	207,474,688	24.3311	8.3967	.001689189	1,859.82	275,253.78
593	351,649	208,527,857	24.3516	8.4014	.001686341	1,862.96	276,184.48
594	352,836	209,584,584	24.3721	8.4061	.001683502	1,866.11	277,116.75
595	354,025	210,644,875	24.3926	8.4108	.001680672	1,869.25	278,050.58
596	355,216	211,708,736	24.4131	8.4155	.001677852	1,872.39	278,985.99
597	356,409	212,776,173	24.4336	8.4202	.001675042	1,875.53	279.922.97
598	357,604	213,847,192	24.4540	8.4249	.001672241	1,878.67	280,861.52
599	358,801	214,921,799	24.4745	8.4296	.001669449	1,881.81	281,801.65
600	360,000	216,000,000	24.4949	8.4343	.001666667	1,884.96	282,743.34
601	361,201	217,081,801	24.5153	8.4390	.001663894	1,888.10	283,686.60
602	362,404	218,167,208	24.5357	8.4437	.001661130	1,891.24	284,631.44
603	363,609	219,256,227	24.5561	8.4484	.001658375	1,894.38	285,577.84
604	364,816	220,348,864	24.5764	8.4530	.001655629	1,897.52	286,525.82
605	366,025	221,445,125	24.5968	8.4577	.001652893	1,900.66	287,475.36
606	367,236	222,545,016	24.6171	8.4623	.001650165	1,903.81	288,426.48
607	368,449	223,648,543	24.6374	8.4670	.001647446	1,906.95	289,379.17
608	369,664	224,755,712	24.6577	8.4716	.001644737	1,910.09	290,333.43
609	370,881	225,866,529	24.6779	8.4763	.001642036	1,913.23	291,289.26
610	372,100	226,981,000	24.6982	8.4809	.001639344	1,916.37	292,246.66
611	373,321	228,099,131	24.7184	8.4856	.001636661	1,919.51	293,205.63
612	374,544	229,220,928	24.7386	8.4902	.001633987	1,922.65	294,166.17
613	375,769	230,346,397	24.7588	8.4948	.001631321	1,925.80	295,128.28
614	376,996	231,475,544	24.7790	8.4994	.001628664	1,928.94	296,091.97
615	378,225	232,608,375	24.7992	8.5040	.001626016	1,932.08	297,057.22
616	379,456	233,744,896	24.8193	8.5086	.001623377	1,935.22	298,024.05
617	380,689	234,885,113	24.8395	8.5132	.001620746	1,938.36	298,992.44
618	381,924	236,029,032	24.8596	8.5178	.001618123	1,941.50	299,962.41
619	383,161	237,176,659	24.8797	8.5224	.001615509	1,944.65	300,933.95
620	384,400	238,328,000	24.8998	8.5270	.001612903	1,947.79	301,907.05
621	385,641	239,483,061	24.9199	8.5316	.001610306	1,950.93	302,881.73
622	386.884	240,641,848	24.9399	8.5362	.001607717	1,954.07	303,857.98

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
623	388,129	241,804,367	24.9600	8.5408	.001605136	1,957.21	304,835.80
624	389,376	242,970,624	24.9800	8.5453	.001602564	1,960.35	305,815.20
625	390,625	244,140,625	25.0000	8.5499	.001600000	1,963.50	306,796.16
626	391,876	245,314,376	25.0200	8.5544	.001597444	1,966.64	307,778.69
627	393,129	246,491,883	25.0400	8.5589	.001594896	1,969.78	308,762.79
628	394,384	247,673,152	25.0599	8.5635	.001592357	1,972.92	309,748.47
629	395,641	248,858,189	25.0799	8.5681	.001589825	1,976.06	310,735.71
630	396,900	250,047,000	25.0998	8.5726	.001587302	1,979.20	311,724.53
631	398,161	251,239,591	25.1197	8.5772	.001584786	1,982.35	312,714.92
632	399,424	252,435,968	25.1396	8.5817	.001582278	1,985.49	313,706.88
633	400,689	253,636,137	25.1595	8.5862	.001579779	1,988.63	314,700.40
634	401,956	254,840,104	25.1794	8.5907	.001577287	1,991.77	315,695.50
635	403,225	256,047,875	25.1992	8.5952	.001574803	1,994.91	316,692.17
636	404,496	257,259,456	25.2190	8.5997	.001572327	1,998.05	317,690.42
637	405,769	258,474,853	25.2389	8.6043	.001569859	2,001.19	318,690.23
638	407,044	259,694,072	25.2587	8.6088	.001567398	2,004.34	319,691.61
639	408,321	260,917,119	25.2784	8.6132	.001564945	2,007.48	320,694.56
640	409,600	262,144,000	25.2982	8.6177	.001562500	2,010.62	321,699.09
641	410,881	263,374,721	25.3180	8.6222	.001560062	2,013.76	322.705.18
642	412,164	264,609,288	25.3377	8.6267	.001557632	2,016.90	323,712.85
643	413,449	265,847,707	25.3574	8.6312	.001555210	2,020.04	324,722.09
644	414,736	267,089,984	25.3772	8.6357	.001552795	2,023.19	325,732.89
645	416,125	268,336,125	25.3969	8.6401	.001550388	2,026.33	326,745.27
646	417,316	269,585,136	25.4165	8.6446	.001547988	2,029.47	327,759.22
647	418,609	270,840,023	25.4362	8.6490	.001545595	2,032.61	328,774.74
648	419,904	272,097,792	25.4558	8.6535	.001543210	2,035.75	329,791.83
649	421,201	273,359,449	25.4755	8.6579	.001540832	2,038.89	330,810.49
650	422,500	274,625,000	25.4951	8.6624	.001538462	2,042.04	331,830.72
651	423,801	275,894,451	25.5147	8.6668	.001536098	2,045.18	332,852.53
652	425,104	277,167,808	25.5343	8.6713	.001533742	2,048.32	333,875.90
653	426,409	278,445,077	25.5539	8.6757	.001531394	2,051.46	334,900.85
654	427,716	279,726,264	25.5734	8.6801	.001529052	2,054.60	335,927.36
655	429,025	281,011,375	25.5930	8.6845	.001526718	2,057.74	336,955.45
656	430,336	282,300,416	25.6125	8.6890	.001524390	2,060.88	337,985.10
657	431,639	283,593,393	25.6320	8.6934	.001522070	2,064.03	339,016.33
658	432,964	284,890,312	25.6515	8.6978	.001519751	2,067.17	340,049.13
659	434,281	286,191,179	25.6710	8.7022	.001517451	2,070.31	341,083.50
660	435,600	287,496,000	25.6905	8.7066	.001515152	2,073.45	342,119.44
661	436,921	288,804,781	25.7099	8.7110	.001512859	2,076.59	343,156.95
662	438,244	290,117,528	25.7294	8.7154	.001510574	2,079.73	344,196.03
663	439,569	291,434,247	25.7488	8.7198	.001508296	2,082.88	345,236.69
664	440,896	292,754,944	25.7682	8.7241	.001506024	2,086.02	346,278.91
665	442,225	294,079,625	25.7876	8.7285	.001503759	2,089.16	347,322.70
666	443,556	295,408,296	25.8070	8.7329	.001501502	2,092.30	348,368.07
667	444,899	296,740,963	25.8263	8.7373	.001499250	2,095.44	349,415.00
668	446,224	298,077,632	25.8457	8.7416	.001497006	2,098.58	350,463.51
669	447,561	299,418,309	25.8650	8.7460	.001494768	2,101.73	351,513.59
670	448,900	300,763,000	25.8844	8.7503	.001492537	2,104.87	352,565.24
671	450,241	302,111,711	25.9037	8.7547	.001490313	2,108.01	353,618.45
672	451,584	303,464,448	25.9230	8.7590	.001488095	2,111.15	354,673.24
673	452,929	304,821,217	25.9422	8.7634	.001485884	2,114.29	355,729.60
674	454,276	306,182,024	25.9615	8.7677	.001483680	2,117.43	356,787.54
675	455,625	307,546,875	25.9808	8.7721	.001481481	2,120.58	357,847.04
676	456,976	308,915,776	26.0000	8.7764	.001479290	2,123.72	358,908.11
677	458,329	310,288,733	26.0192	8.7807	.001477105	2,126.86	359,970.75
678	459,684	311,665,752	26.0384	8.7850	.001474926	2,130.00	361,034.97
679	461,041	313,046,839	26.0576	8.7893	.001472754	2,133.14	362,100.75
680	462,400	314,432,000	26.0768	8.7937	.001470588	2,136.28	363,168.11
681	463,761	315,821,241	26.0960	8.7980	.001468429	2,139.42	364,237.04
682	465,124	317,214,568	26.1151	8.8023	.001466276	2,142.57	365,307.54
683	466,489	318,611,987	26.1343	8.8066	.001464129	2,145.71	366,379.60
684	467,856	320,013,504	26.1534	8.8109	.001461988	2,148.85	367,453.24
685	469,225	321,419,125	26.1725	8.8152	.001459854	2,151.99	368,528.45

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
686	470,596	322,828,856	26.1916	8.8194	.001457726	2,155.13	369,605.23
687	471,969	324,242,703	26.2107	8.8237	.001455604	2,158.27	370,683.59
688	473,344	325,660,672	26.2298	8.8280	.001453488	2,161.42	371,763.51
689	474,721	327,082,769	26.2488	8.8323	.001451379	2,164.56	372,845.00
690	476,100	328,509,000	26.2679	8.8366	.001449275	2,167.70	373,928.07
691	477,481	329,939,371	26.2869	8.8408	.001447178	2,170.84	375,012.70
692	478,864	331,373,888	26.3059	8.8451	.001445087	2,173.98	376,098.91
693	480,249	332,812,557	26.3249	8.8493	.001443001	2,177.12	377,186.68
694	481,636	334,255,384	26.3439	8.8536	.001440922	2,180.27	378,276.03
695	483,025	335,702,375	26.3629	8.8578	.001438849	2,183.41	379,366.95
696	484,416	337,153,536	26.3818	8.8621	.001436782	2,186.55	380,459.44
697	485,809	338,608,873	26.4008	8.8663	.001434720	2,189.69	381,553.50
698	487,204	340,068,392	26.4197	8.8706	.001432665	2,192.83	382,649.13
699	488,601	341,532,099	26.4386	8.8748	.001430615	2,195.97	383,746.33
700	490,000	343,000,000	26.4575	8.8790	.001428571	2,199.11	384,845.10
701	491,401	344,472,101	26.4764	8.8833	.001426534	2,202.26	385,945.44
702	492,804	345,948,408	26.4953	8.8875	.001424501	2,205.40	387,047.36
703	494,209	347,428,927	26.5141	8.8917	.001422475	2,208.54	388,150.84
704	495,616	348,913,664	26.5330	8.8959	.001420455	2,211.68	389,255.90
705	497,025	350,402,625	26.5518	8.9001	.001418440	2,214.82	390,362.52
706	498,436	351,895,816	26.5707	8.9043	.001416431	2,217.96	391,470.72
707	499,849	353,393,243	26.5895	8.9085	.001414427	2,221.11	392,580.49
708	501,264	354,894,912	26.6083	8.9127	.001412429	2,224.25	393,691.82
709	502,681	356,400,829	26.6271	8.9169	.001410437	2,227.39	394,804.73
710	504,100	357,911,000	26.6458	8.9211	.001408451	2,230.53	395,919.21
711	505,521	359,425,431	26.6646	8.9253	.001406470	2,233.67	397,035.26
712	506,944	360,944,128	26.6833	8.9295	.001404494	2,236.81	398,152.89
713	508,369	362,467,097	26.7021	8.9337	.001402525	2,239.96	399,272.08
714	509,796	363,994,344	26.7208	8.9378	.001400560	2,243.10	400,392.84
715	511,225	365,525,875	26.7395	8.9420	.001398601	2,246.24	401,515.18
716	512,656	367,061,696	26.7582	8.9462	.001396648	2,249.38	402,639.08
717	514,089	368,601,813	26.7769	8.9503	.001394700	2,252.52	403,764.56
718	515,524	370,146,232	26.7955	8.9545	.001392758	2,255.66	404,891.60
719	516,961	371,694,959	26.8142	8.9587	.001390821	2,258.81	406,020.22
720	518,400	373,248,000	26.8328	8.9628	.001388889	2,261.95	407,150.41
721	519,841	374,805,361	26.8514	8.9670	.001386963	2,265.09	408,282.17
722	521,284	376,367,048	26.8701	8.9711	.001385042	2,268.23	409,415.50
723	522,729	377,933,067	26.8887	8.9752	.001383126	2,271.37	410,550.40
724	524,176	379,503,424	26.9072	8.9794	.001381215	2,274.51	411,686.87
725	525,625	381,078,125	26.9258	8.9835	.001379310	2,277.65	412,824.91
726	527,076	382,657,176	26.9444	8.9876	.001377410	2,280.80	413,964.52
727	528,529	384,240,583	26.9629	8.9918	.001375516	2,283.94	415,105.71
728	529,984	385,828,352	26.9815	8.9959	.001373626	2,287.08	416,248.46
729	531,441	387,420,489	27.0000	9.0000	.001371742	2,290.22	417,392.79
730	532,900	389,017,000	27.0185	9.0041	.001369863	2,293.36	418,538.68
731	534,361	390,617,891	27.0370	9.0082	.001367989	2,296.50	419,686.15
732	535,824	392,223,168	27.0555	9.0123	.001366120	2,299.65	420,835.19
733	537,289	393,832,837	27.0740	9.0164	.001364256	2,302.79	421,985.79
734	538,756	395,446,904	27.0924	9.0205	.001362398	2,305.93	423,137.97
735	540,225	397,065,375	27.1109	9.0246	.001360544	2,309.07	424,291.72
736	541,696	398,688,256	27.1293	9.0287	.001358696	2,312.21	425,447.04
737	543,169	400,315,553	27.1477	9.0328	.001356852	2,315.35	426,603.94
738	544,644	401,947,272	27.1662	9.0369	.001355014	2,318.50	427,762.40
739	546,121	403,583,419	27.1846	9.0410	.001353180	2,321.64	428,922.43
740	547,600	405,224,000	27.2029	9.0450	.001351351	2,324.78	430,084.03
741	549,801	406,869,021	27.2213	9.0491	.001349528	2,327.92	431,247.21
742	550,564	408,518,488	27.2397	9.0532	.001347709	2,331.06	432,411.95
743	552,049	410,172,407	27.2580	9.0572	.001345895	2,334.20	433,578.27
744	553,536	411,830,784	27.2764	9.0613	.001344086	2,337.34	434,746.16
745	555,025	413,493,625	27.2947	9.0654	.001342282	2,340.49	435,915.62
746	556,516	415,160,936	27.3130	9.0694	.001340483	2,343.63	437,086.64
747	558,009	416,832,723	27.3313	9.0735	.001338688	2,346.77	438,259.24
748	559,504	418,508,992	27.3496	9.0775	.001336898	2,349.91	439,433.41

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
749	561,001	420,189,749	27.3679	9.0816	.001335113	2,353.05	440,609.16
750	562,500	421,875,000	27.3861	9.0856	.001333333	2,356.19	441,786.47
751	564,001	423,564,751	27.4044	9.0896	.001331558	2,359.34	442,965.35
752	565,504	425,259,008	27.4226	9.0937	.001329787	2,362.48	444,145.80
753	567,009	426,957,777	27.4408	9.0977	.001328021	2,365.62	445,327.83
754	568,516	428,661,064	27.4591	9.1017	.001326260	2,368.76	446,511.42
755	570,025	430,368,875	27.4773	9.1057	.001324503	2,371.90	447,696.59
756	571,536	432,081,216	27.4955	9.1098	.001322751	2,375.04	448,883.32
757	573,049	433,798,093	27.5136	9.1138	.001321004	2,378.19	450,071.63
758	574,564	435,519,512	27.5318	9.1178	.001319261	2,381.33	451,261.51
759	576,081	437,245,479	27.5500	9.1218	.001317523	2,384.47	452,452.96
760	577,600	438,976,000	27.5681	9.1258	.001315789	2,387.61	453,645.98
761	579,121	440,711,081	27.5862	9.1298	.001314060	2,390.75	454,840.57
762	580,644	442,450,728	27.6043	9.1338	.001312336	2,393.89	456,036.73
763	582,169	444,194,947	27.6225	9.1378	.001310616	2,397.04	457,234.46
764	583,696	445,943,744	27.6405	9.1418	.001308901	2,400.18	458,433.77
765	585,225	447,697,125	27.6586	9.1458	.001307190	2,403.32	459,634.64
766	586,756	449,455,096	27.6767	9.1498	.001305483	2,406.46	460,837.08
767	588,289	451,217,663	27.6948	9.1537	.001303781	2,409.60	462,041.10
768	589,824	452,984,832	27.7128	9.1577	.001302083	2,412.74	463,246.69
769	591,361	454,756,609	27.7308	9.1617	.001300390	2,415.88	464,453.84
770	592,900	456,533,000	27.7489	9.1657	.001298701	2,419.03	465,662.57
771	594,441	458,314,011	27.7669	9.1696	.001297017	2,422.17	466,872.87
772	595,984	460,099,648	27.7849	9.1736	.001295337	2,425.31	468,084.74
773	597,529	461,889,917	27.8029	9.1775	.001293661	2,428.45	469,298.18
774	599,076	463,684,824	27.8209	9.1815	.001291990	2,431.59	470,513.19
775	600,625	465,484,375	27.8388	9.1855	.001290323	2,434.73	471,729.77
776	602,176	467,288,576	27.8568	9.1894	.001288660	2,437.88	472,947.92
777	603,729	469,097,433	27.8747	9.1933	.001287001	2,441.02	474,167.65
778	605,284	470,910,952	27.8927	9.1973	.001285347	2,444.16	475,388.94
779	606,841	472,729,139	27.9106	9.2012	.001283697	2,447.30	476,611.81
780	608,400	474,552,000	27.9285	9.2052	.001282051	2,450.44	477,836.24
781	609,961	476,379,541	27.9464	9.2091	.001280410	2,453.58	479,062.25
782	611,524	478,211,768	27.9643	9.2130	.001278772	2,456.73	480,289.83
783	613,089	480,048,687	27.9821	9.2170	.001277139	2,459.87	481,518.97
784	614,656	481,890,304	28.0000	9.2209	.001275510	2,463.01	482,749.69
785	616,225	483,736,625	28.0179	9.2248	.001273885	2,466.15	483,981.98
786	617,796	485,587,656	28.0357	9.2287	.001272265	2,469.29	485,215.84
787	619,369	487,443,403	28.0535	9.2326	.001270648	2,472.43	486,451.28
788	620,944	489,303,872	28.0713	9.2365	.001269036	2,475.58	487,688.28
789	622,521	491,169,069	28.0891	9.2404	.001267427	2,478.72	488,926.85
790	624,100	493,039,000	28.1069	9.2443	.001265823	2,481.86	490,166.99
791	625,681	494,913,671	28.1247	9.2482	.001264223	2,485.00	491,408.71
792	627,264	496,793,088	28.1425	9.2521	.001262626	2,488.14	492,651.99
793	628,849	498,677,257	28.1603	9.2560	.001261034	2,491.28	493,896.85
794	630,436	500,566,184	28.1780	9.2599	.001259446	2,494.42	495,143.28
795	632,025	502,459,875	28.1957	9.2638	.001257862	2,497.57	496,391.27
796	633,616	504,358,336	28.2135	9.2677	.001256281	2,500.71	497,640.84
797	635,209	506,261,573	28.2312	9.2716	.001254705	2,503.85	498,891.98
798	636,804	508,169,592	28.2489	9.2754	.001253133	2,506.99	500,144.69
799	638,401	510,082,399	28.2666	9.2793	.001251364	2,510.13	501,398.97
800	640,000	512,000,000	28.2843	9.2832	.001250000	2,513.27	502,654.82
801	641,601	513,922,401	28.3019	9.2870	.001248439	2,516.42	503,912.25
802	643,204	515,849,608	28.3196	9.2909	.001246883	2,519.56	505,171.24
803	644,809	517,781,627	28.3373	9.2948	.001245330	2,522.70	506,431.80
804	646,416	519,718,464	28.3549	9.2986	.001243781	2,525.84	507,693.94
805	648,025	521,660,125	28.3725	9.3025	.001242236	2,528.98	508,957.64
806	649,636	523,606,616	28.3901	9.3063	.001240695	2,532.12	510,222.92
807	651,249	525,557,943	28.4077	9.3102	.001239157	2,535.27	511,489.77
808	652,864	527,514,112	28.4253	9.3140	.001237624	2,538.41	512,758.19
809	654,481	529,475,129	28.4429	9.3179	.001236094	2,541.55	514,028.18
810	656,100	531,441,000	28.4605	9.3217	.001234568	2,544.69	515,299.74
811	657,721	533,411,731	28.4781	9.3255	.001233046	2,547.83	516,572.87

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
812	659,344	535,387,328	28.4956	9.3294	.001231527	2,550.97	517,847.57
813	660,969	537,367,797	28.5132	9.3332	.001230012	2,554.11	519,123.84
814	662,596	539,353,144	28.5307	9.3370	.001228501	2,557.26	520,401.68
815	664,225	541,343,375	28.5482	9.3408	.001226994	2,560.40	521,681.10
816	665,856	543,338,496	28.5657	9.3447	.001225490	2,563.54	522,962.08
817	667,489	545,338,513	28.5832	9.3485	.001223990	2,566.68	524,244.63
818	669,124	547,343,432	28.6007	9.3523	.001222494	2,569.82	525,528.76
819	670,761	549,353,259	28.6182	9.3561	.001221001	2,572.96	526,814.46
820	672,400	551,368,000	28.6356	9.3599	.001219512	2,576.11	528,101.73
821	674,041	553,387,661	28.6531	9.3637	.001218027	2,579.25	529,390.56
822	675,584	555,412,248	28.6705	9.3675	.001216545	2,582.39	530,680.97
823	677,329	557,441,767	28.6880	9.3713	.001215067	2,585.53	531,972.95
824	678,976	559,476,224	28.7054	9.3751	.001213592	2,588.67	533,266.50
825	680,625	561,515,625	28.7228	9.3789	.001212121	2,591.81	534,561.62
826	682,276	563,559,976	28.7402	9.3827	.001210654	2,594.96	535,858.32
827	683,929	565,609,283	28.7576	9.3865	.001209190	2,598.10	537,156.58
828	685,584	567,663,552	28.7750	9 3902	.001207729	2,601.24	538,456.41
829	687,241	569,722,789	28.7924	9.3940	.001206273	2,604.38	539,757.82
830	688,900	571,787,000	28.8097	9.3978	.001204819	2,607.52	541,060.79
831	690,561	573,856,191	28.8271	9.4016	.001203369	2,610.66	542,365.34
832	692,224	575,930,368	28.8444	9.4053	.001201923	2,613.81	543,671.46
833	693,889	578,009,537	28.8617	9.4091	.001200480	2,616.95	544,979.15
834	695,556	580,093,704	28.8791	9.4129	.001199041	2,620.09	546,288.40
835	697,225	582,182,875	28.8964	9.4166	.001197605	2,623.23	547,599.23
836	698,896	584,277,056	28.9137	9.4204	.001196172	2,626.37	548,911.63
837	700,569	586,376,253	28.9310	9.4241	.001194743	2,629.51	550,225.61
838	702,244	588,480,472	28.9482	9.4279	.001193317	2,632.65	551,541.15
839	703,921	590,589,719	28.9655	9.4316	.001191895	2,635.80	552,858.26
840	705,600	592,704,000	28.9828	9.4354	.001190476	2,638.94	554,176.94
841	707,281	594,823,321	29.0000	9.4391	.001189061	2,642.08	555,497.20
842	708,964	596,947,688	29.0172	9.4429	.001187648	2,645.22	556,819.02
843	710,649	599,077,107	29.0345	9.4466	.001186240	2,648.36	558,142.42
844	712,336	601,211,584	29.0517	9.4503	.001184834	2,651.50	559,467.39
845	714,025	603,351,125	29.0689	9.4541	.001183432	2,654.65	560,793.92
846	715,716	605,495,736	29.0861	9.4578	.001182033	2,657.79	562,122.03
847	717,409	607,645,423	29.1033	9.4615	.001180638	2,660.93	563,451.71
848	719,104	609,800,192	29.1204	9.4652	.001179245	2,664.07	564,782.96
849	720,801	611,960,049	29.1376	9.4690	.001177856	2,667.21	566,115.78
850	722,500	614,125,000	29.1548	9.4727	.001176471	2,670.35	567,450.17
851	724,201	616,295,051	29.1719	9.4764	.001175088	2,673.50	568,786.14
852	725,904	618,470,208	29.1890	9.4801	.001173709	2,676.64	570,123.67
853	727,609	620,650,477	29.2062	9.4838	.001172333	2,679.78	571,462.77
854	729,316	622,835,864	29.2233	9.4875	.001170960	2,682.92	572,803.45
855	731,025	625,026,375	29.2404	9.4912	.001169591	2,686.06	574,145.69
856	732,736	627,222,016	29.2575	9.4949	.001168224	2,689.20	575,489.51
857	734,449	629,422,793	29.2746	9.4986	.001166861	2,692.34	576,834.90
858	736,164	631,628,712	29.2916	9.5023	.001165501	2,695.49	578,181.85
859	737,881	633,839,779	29.3087	9.5060	.001164144	2,698.63	579,530.38
860	739,600	636,056,000	29.3258	9.5097	.001162791	2,701.77	580,880.48
861	741,321	638,277,381	29.3428	9.5135	.001161440	2,704.91	582,232.15
862	743,044	640,503,928	29.3598	9.5171	.001160093	2,708.05	583,585.39
863	744,769	642,735,647	29.3769	9.5207	.001158749	2,711.19	584,940.20
864	746,496	644,972,544	29.3939	9.5244	.001157407	2,714.34	586,296.59
865	748,225	647,214,625	29.4109	9.5281	.001156069	2,717.48	587,654.54
866	749,956	649,461,896	29.4279	9.5317	.001154734	2,720.62	589,014.07
867	751,689	651,714,363	29.4449	9.5354	.001153403	2,723.76	590,375.16
868	753,424	653,972,032	29.4618	9.5391	.001152074	2,726.90	591,737.83
869	755,161	656,234,909	29.4788	9.5427	.001150748	2,730.04	593,102.06
870	756,900	658,503,000	29.4958	9.5464	.001149425	2,733.19	594,467.87
871	758,641	660,776,311	29.5127	9.5501	.001148106	2,736.33	595,835.25
872	760,384	663,054,848	29.5296	9.5537	.001146789	2,739.47	597,204.20
873	762,129	665,338,617	29.5466	9.5574	.001145475	2,742.61	598,574.72
874	763,876	667,627,624	29.5635	9.5610	.001144165	2,745.75	599,946.81

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
875	765,625	669,921,875	29.5804	9.5647	.001142857	2,748.89	601,320.47
876	767,376	672,221,376	29.5973	9.5683	.001141553	2,752.04	602,695.70
877	769,129	674,526,133	29.6142	9.5719	.001140251	2,755.18	604,072.50
878	770,884	676,836,152	29.6311	9.5756	.001138952	2,758.32	605,450.88
879	772,641	679,151,439	29.6479	9.5792	.001137656	2,761.46	606,830.82
880	774,400	681,472,000	29.6648	9.5828	.001136364	2,764.60	608,212.34
881	776,161	683,797,841	29.6816	9.5865	.001135074	2,767.74	609,595.42
882	777,924	686,128,968	29.6985	9.5901	.001133787	2,770.88	610,980.08
883	779,689	688,465,387	29.7153	9.5937	.001132503	2,774.03	612,366.31
884	781,456	690,807,104	29.7321	9.5973	.001131222	2,777.17	613,754.11
885	783,225	693,154,125	29.7489	9.6010	.001129944	2,780.31	615,143.48
886	784,996	695,506,456	29.7658	9.6046	.001128668	2,783.45	616,534.42
887	786,769	697,864,103	29.7825	9.6082	.001127396	2,786.59	617,926.93
888	788,544	700,227,072	29.7993	9.6118	.001126126	2,789.73	619,321.01
889	790,321	702,595,369	29.8161	9.6154	.001124859	2,792.88	620,716.66
890	792,100	704,969,000	29.8329	9.6190	.001123596	2,796.02	622,113.89
891	793,881	707,347,971	29.8496	9.6226	.001122334	2,799.16	623,512.68
892	795,664	707,932,288	29.8664	9.6262	.001121076	2,802.30	624,913.04
893	797,449	712,121,957	29.8831	9.6298	.001119821	2,805.44	626,314.98
894	799,236	714,516,984	29.8998	9.6334	.001118568	2,808.58	627,718.49
895	801,025	716,917,375	29.9166	9.6370	.001117818	2,811.73	629,123.56
896	802,816	719,323,136	29.9333	9.6406	.001116071	2,814.87	630,530.21
897	804,609	721,734,273	29.9500	9.6442	.001114827	2,818.01	631,938.43
898	806,404	724,150,792	29.9666	9.6477	.001113586	2,821.15	633,348.22
899	808,201	726,572,699	29.9833	9.6513	.001112347	2,824.29	634,759.58
900	810,000	729,000,000	30.0000	9.6549	.001111111	2,827.43	636,172.51
901	811,801	731,432,701	30.0167	9.6585	.001109878	2,830.58	637,587.01
902	813,604	733,870,808	30.0333	9.6620	.001108647	2,833.72	639,003.09
903	815,409	736,314,327	30.0500	9.6656	.001107420	2,836.86	640,420.73
904	817,216	738,763,264	30.0666	9.6692	.001106195	2,840.00	641,839.95
905	819,025	741,217,625	30.0832	9.6727	.001104972	2,843.14	643,260.73
906	820,836	743,677,416	30.0998	9.6763	.001103753	2,846.28	644,683.09
907	822,649	746,142,643	30.1164	9.6799	.001102536	2,849.42	646,107.01
908	824,464	748,613,312	30.1330	9.6834	.001101322	2,852.57	647,532.51
909	826,281	751,089,429	30.1496	9.6870	.001100110	2,855.71	648,959.58
910	828,100	753,571,000	30.1662	9.6905	.001098901	2,858.85	650,388.22
911	829,921	756,058,031	30.1828	9.6941	.001091695	2,861.99	651,818.43
912	831,744	758,550,825	30.1993	9.6976	.001096491	2,865.13	653,250.21
913	833,569	761,048,497	30.2159	9.7012	.001095290	2,868.27	654,683.56
914	835,396	763,551,944	30.2324	9.7047	.001094092	2,871.42	656,118.48
915	837,225	766,060,875	30.2490	9.7082	.001092896	2,874.56	657,554.98
916	839,056	768,575,296	30.2655	9.7118	.001091703	2,877.70	658,993.04
917	840,889	771,095,213	30.2820	9.7153	.001090513	2,880.84	660,432.68
918	842,724	773,620,632	30.2985	9.7188	.001089325	2,883.98	661,873.88
919	844,561	776,151,559	30.3150	9.7224	.001088139	2.887.12	663,316.66
920	846,400	778,688,000	30.3315	9.7259	.001086957	2,890.27	664,761.01
921	848,241	781,229,961	30.3480	9.7294	.001085776	2,893.41	666,206.92
922	850,084	783,777,448	30.3645	9.7329	.001084599	2,896.55	667,654.41
923	851,929	786,330,467	30.3809	9.7364	.001083423	2,899.69	669,103.47
924	853,776	788,889,024	30.3974	9.7400	.001082251	2,902.83	670,554.10
925	855,625	791,453,125	30.4138	9.7435	.001081081	2,905.97	672,006.30
926	857,476	794,022,776	30.4302	9.7470	.001079914	2,909.11	673,460.08
927	859,329	796,597,983	30.4467	9.7505	.001078749	2,912.26	674,915.42
928	861,184	799,178,752	30.4631	9.7540	.001077586	2,915.40	676,372.33
929	863,041	801,765,089	30.4795	9.7575	.001076426	2,918.54	677,830.82
930	864,900	804,357,000	30.4959	9.7610	.001075269	2,921.68	679,290.87
931	866,761	806,954,491	30.5123	9.7645	.001074114	2,924.82	680,752.50
932	868,624	809,557,568	30.5287	9.7680	.001072961	2,927.96	682,215.69
933	870,489	812,166,237	30.5450	9.7715	.001071811	2,931.11	683,680.46
934	872,356	814,780,504	30.5614	9.7750	.001070664	2,934.25	685,146.80
935	874,225	817,400,375	30.5778	9.7785	.001069519	2,937.39	686,614.71
936	876,096	820,025,856	30.5941	9.7829	.001068376	2,940.53	688,084.19
937	877,969	822,656,953	30.6105	9.7854	.001067236	2,943.67	689,555.24

No.	Square.	Cube.	Sq. Root.	Cu. Root.	Reciprocal.	Circum.	Area.
938	879,844	825,293,672	30.6268	9.7889	.001066098	2,946.81	691,027.86
939	881,721	827,936,019	30.6431	9.7924	.001064963	2,949.96	692,502.05
940	883,600	830,584,000	30.6594	9.7959	.001063830	2,953.10	693,977.82
941	885,481	833,237,621	30.6757	9.7993	.001062699	2,956.24	695,455.15
942	887,364	835,896,888	30.6920	9.8028	.001061571	2,959.38	696,934.06
943	889,249	838,561,807	30.7083	9.8063	.001060445	2,962.52	698,414.53
944	891,136	841,232,384	30.7246	9.8097	.001059322	2,965.66	699,896.58
945	893,025	843,908,625	30.7409	9.8132	.001058201	2,968.81	701,380.19
946	894,916	846,590,536	30.7571	9.8167	.001057082	2,971.95	702,865.38
947	896,808	849,278,123	30.7734	9.8201	.001055966	2,975.09	704,352.14
948	898,704	851,971,392	30.7896	9.8236	.001054852	2,978.23	705,840.47
949	900,601	854,670,349	30.8058	9.8270	.001053741	2,981.37	707,330.37
950	902,500	857,375,000	30.8221	9.8305	.001052632	2,984.51	708,821.84
951	904,401	860,085,351	30.8383	9.8339	.001051525	2,987.65	710,314.88
952	906,304	862,801,408	30.8545	9.8374	.001050420	2,990.80	711,809.50
953	908,209	865,523,177	30.8707	9.8408	.001049318	2,993.94	713,305.68
954	910,116	868,250,664	30.8869	9.8443	.001048218	2,997.08	714,803.43
955	912,025	870,983,875	30.9031	9.8477	.001047120	3,000.22	716,302.76
956	913,936	873,722,816	30.9192	9.8511	.001046025	3,003.36	717,803.66
957	915,849	876,467,493	30.9354	9.8546	.001044932	3,006.50	719,306.12
958	917,764	879,217,912	30.9516	9.8580	.001043841	3,009.65	720,810.16
959	919,681	881,974,079	30.9677	9.8614	.001042753	3,012.79	722,315.77
960	921,600	884,736,000	30.9839	9.8648	.001041667	3,015.93	723,822.95
961	923,521	887,503,681	31.0000	9.8683	.001040583	3,019.07	725,331.70
962	925,444	890,277,128	31.0161	9.8717	.001039501	3,022.21	726,842.02
963	927,369	893,056,347	31.0322	9.8751	.001038422	3,025.35	728,353.91
964	929,296	895,841,344	31.0483	9.8785	.001037344	3,028.50	729,867.37
965	931,225	898,632,125	31.0644	9.8819	.001036269	3,031.64	731,382.40
966	933,156	901,428,696	31.0805	9.8854	.001035197	3,034.78	732,899.01
967	935,089	904,231,063	31.0966	9.8888	.001034126	3,037.92	734,417.18
968	937,024	907,039,232	31.1127	9.8922	.001033058	3,041.06	735,936.93
969	938,961	909,853,209	31.1288	9.8956	.001031992	3,044.20	737,458.24
970	940,900	912,673,000	31.1448	9.8990	.001030928	3,047.34	738,981.13
971	942,841	915,498,611	31.1609	9.9024	.001029866	3,050.49	740,505.59
972	944,784	918,330,048	31.1769	9.9058	.001028807	3,053.63	742,031.62
973	946,729	921,167,317	31.1929	9.9092	.001027749	3,056.77	743,559.22
974	948,676	924,010,424	31.2090	9.9126	.001026694	3,059.91	745,088.39
975	950,625	926,859,375	31.2250	9.9160	.001025641	3,063.05	746,619.13
976	952,576	929,714,176	31.2410	9.9194	.001024590	3,066.19	748,151.44
977	954,529	932,574,833	31.2570	9.9228	.001023541	3,069.34	749,685.32
978	956,484	935,441,352	31.2730	9.9261	.001022495	3,072.48	751,220.78
979	958,441	938,313,739	31.2890	9.9295	.001021450	3,075.62	752,757.80
980	960,400	941,192,000	31.3050	9.9329	.001020408	3,078.76	754,296.40
981	962,361	944,076,141	31.3209	9.9363	.001019168	3,081.90	755,836.56
982	964,324	946,966,168	31.3369	9.9396	.001018330	3,085.04	757,378.30
983	966,289	949,862,087	31.3528	9.9430	.001017294	3,088.19	758,921.61
984	968,256	952,763,904	31.3688	9.9464	.001016260	3,091.33	760,466.48
985	970,225	955,671,625	31.3847	9.9497	.001015228	3,094.47	762,012.93
986	972,196	958,585,256	31.4006	9.9531	.001014199	3,097.61	763,560.95
987	974,169	961,504,803	31.4166	9.9565	.001013171	3,100.75	765,110.54
988	976,144	964,430,272	31.4325	9.9598	.001012146	3,103.89	766,661.70
989	978,121	967,361,669	31.4484	9.9632	.001011122	3,107.04	768,214.44
990	980,100	970,299,000	31.4643	9.9666	.001010101	3,110.18	769,768.74
991	982,081	973,242,271	31.4802	9.9699	.001009082	3,113.32	771,324.61
992	984,064	976,191,488	31.4960	9.9733	.001008065	3,116.46	772,882.06
993	986,049	979,146,657	31.5119	9.9766	.001007049	3,119.60	774,441.07
994	988,036	982,107,784	31.5278	9.9800	.001006036	3,122.74	776,001.66
995	990,025	985,074,875	31.5436	9.9833	.001005025	3,125.88	777,563.82
996	992,016	988,047,936	31.5595	9.9866	.001004016	3,129.03	779,127.54
997	994,009	991,026,973	31.5753	9.9900	.001003009	3,132.17	780,692.84
998	996,004	994,011,992	31.5911	9.9933	.001002004	3,135.31	782,259.71
999	998,001	997,002,999	31.6070	9.9967	.001001001	3,138.45	783,828.15
1000	1,000,000	1,000,000,000	31.6228	10.0000	.001000000	3,141.59	785,398.16

CIRCUMFERENCES AND AREAS OF CIRCLES FROM 1-64 TO 100.

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
$\frac{1}{64}$	.0491	.0002	6	18.8496	28.2744	$13\frac{1}{8}$	41.2335	135.297
$\frac{1}{32}$	.0982	.0008	$6\frac{1}{8}$	19.2423	29.4648	$13\frac{1}{4}$	41.6262	137.887
$\frac{1}{16}$	.1963	.0031	$6\frac{1}{4}$	19.6350	30.6797	$13\frac{3}{8}$	42.0189	140.501
$\frac{1}{8}$	.3927	.0123	$6\frac{3}{8}$	20.0277	31.9191	$13\frac{1}{2}$	42.4116	143.139
$\frac{3}{16}$	.5890	.0276	$6\frac{1}{2}$	20.4204	33.1831	$13\frac{5}{8}$	42.8043	145.802
$\frac{1}{4}$	.7854	.0491	$6\frac{5}{8}$	20.8131	34.4717	$13\frac{3}{4}$	43.1970	148.490
$\frac{5}{16}$	.9817	.0767	$6\frac{3}{4}$	21.2058	35.7848	$13\frac{7}{8}$	43.5897	151.202
$\frac{3}{8}$	1.1781	.1104	$6\frac{7}{8}$	21.5985	37.1224	14	43.9824	153.938
$\frac{7}{16}$	1.3744	.1503	7	21.9912	38.4846	$14\frac{1}{8}$	44.3751	156.700
$\frac{1}{2}$	1.5708	.1963	$7\frac{1}{8}$	22.3839	39.8713	$14\frac{1}{4}$	44.7678	159.485
$\frac{9}{16}$	1.7671	.2485	$7\frac{1}{4}$	22.7766	41.2826	$14\frac{3}{8}$	45.1605	162.296
$\frac{5}{8}$	1.9635	.3068	$7\frac{3}{8}$	23.1693	42.7184	$14\frac{1}{2}$	45.5532	165.130
$\frac{11}{16}$	2.1598	.3712	$7\frac{1}{2}$	23.5620	44.1787	$14\frac{5}{8}$	45.9459	167.990
$\frac{3}{4}$	2.3562	.4418	$7\frac{5}{8}$	23.9547	45.6636	$14\frac{3}{4}$	46.3386	170.874
$\frac{13}{16}$	2.5525	.5185	$7\frac{3}{4}$	24.3474	47.1731	$14\frac{7}{8}$	46.7313	173.782
$\frac{7}{8}$	2.7489	.6013	$7\frac{7}{8}$	24.7401	48.7071	15	47.1240	176.715
$\frac{15}{16}$	2.9452	.6903	8	25.1328	50.2656	$15\frac{1}{8}$	47.5167	179.673
1	3.1416	.7854	$8\frac{1}{8}$	25.5255	51.8487	$15\frac{1}{4}$	47.9094	182.655
$1\frac{1}{8}$	3.5343	.9940	$8\frac{1}{4}$	25.9182	53.4563	$15\frac{3}{8}$	48.3021	185.661
$1\frac{1}{4}$	3.9270	1.2272	$8\frac{3}{8}$	26.3109	55.0884	$15\frac{1}{2}$	48.6948	188.692
$1\frac{3}{8}$	4.3197	1.4849	$8\frac{1}{2}$	26.7036	56.7451	$15\frac{5}{8}$	49.0875	191.748
$1\frac{1}{2}$	4.7124	1.7671	$8\frac{5}{8}$	27.0963	58.4264	$15\frac{3}{4}$	49.4802	194.828
$1\frac{5}{8}$	5.1051	2.0739	$8\frac{3}{4}$	27.4890	60.1322	$15\frac{7}{8}$	49.8729	197.933
$1\frac{3}{4}$	5.4978	2.4053	$8\frac{7}{8}$	27.8817	61.8625	16	50.2656	201.062
$1\frac{7}{8}$	5.8905	2.7612	9	28.2744	63.6174	$16\frac{1}{8}$	50.6583	204.216
2	6.2832	3.1416	$9\frac{1}{8}$	28.6671	65.3968	$16\frac{1}{4}$	51.0510	207.395
$2\frac{1}{8}$	6.6759	3.5466	$9\frac{1}{4}$	29.0598	67.2008	$16\frac{3}{8}$	51.4437	210.598
$2\frac{1}{4}$	7.0686	3.9761	$9\frac{3}{8}$	29.4525	69.0293	$16\frac{1}{2}$	51.8364	213.825
$2\frac{3}{8}$	7.4613	4.4301	$9\frac{1}{2}$	29.8452	70.8823	$16\frac{5}{8}$	52.2291	217.077
$2\frac{1}{2}$	7.8540	4.9087	$9\frac{5}{8}$	30.2379	72.7599	$16\frac{3}{4}$	52.6218	220.354
$2\frac{5}{8}$	8.2467	5.4119	$9\frac{3}{4}$	30.6306	74.6621	$16\frac{7}{8}$	53.0145	223.655
$2\frac{3}{4}$	8.6394	5.9396	$9\frac{7}{8}$	31.0233	76.589	17	53.4072	226.981
$2\frac{7}{8}$	9.0321	6.4918	10	31.4160	78.540	$17\frac{1}{8}$	53.7999	230.331
3	9.4248	7.0686	$10\frac{1}{8}$	31.8087	80.516	$17\frac{1}{4}$	54.1926	233.706
$3\frac{1}{8}$	9.8175	7.6699	$10\frac{1}{4}$	32.2014	82.516	$17\frac{3}{8}$	54.5853	237.105
$3\frac{1}{4}$	10.2102	8.2958	$10\frac{3}{8}$	32.5941	84.541	$17\frac{1}{2}$	54.9780	240.529
$3\frac{3}{8}$	10.6029	8.9462	$10\frac{1}{2}$	32.9868	86.590	$17\frac{5}{8}$	55.3707	243.977
$3\frac{1}{2}$	10.9956	9.6211	$10\frac{5}{8}$	33.3795	88.664	$17\frac{3}{4}$	55.7634	247.450
$3\frac{5}{8}$	11.3883	10.3206	$10\frac{3}{4}$	33.7722	90.763	$17\frac{7}{8}$	56.1561	250.948
$3\frac{3}{4}$	11.7810	11.0447	$10\frac{7}{8}$	34.1649	92.886	18	56.5488	254.470
$3\frac{7}{8}$	12.1737	11.7933	11	34.5576	95.033	$18\frac{1}{8}$	56.9415	258.016
4	12.5664	12.5664	$11\frac{1}{8}$	34.9503	97.205	$18\frac{1}{4}$	57.3342	261.587
$4\frac{1}{8}$	12.9591	13.3641	$11\frac{1}{4}$	35.3430	99.402	$18\frac{3}{8}$	57.7269	265.183
$4\frac{1}{4}$	13.3518	14.1863	$11\frac{3}{8}$	35.7357	101.623	$18\frac{1}{2}$	58.1196	268.803
$4\frac{3}{8}$	13.7445	15.0330	$11\frac{1}{2}$	36.1284	103.869	$18\frac{5}{8}$	58.5123	272.448
$4\frac{1}{2}$	14.1372	15.9043	$11\frac{5}{8}$	36.5211	106.139	$18\frac{3}{4}$	58.9050	276.117
$4\frac{5}{8}$	14.5299	16.8002	$11\frac{3}{4}$	36.9138	108.434	$18\frac{7}{8}$	59.2977	279.811
$4\frac{3}{4}$	14.9226	17.7206	$11\frac{7}{8}$	37.3065	110.754	19	59.6904	283.529
$4\frac{7}{8}$	15.3153	18.6555	12	37.6992	113.098	$19\frac{1}{8}$	60.0831	287.272
5	15.7080	19.6350	$12\frac{1}{8}$	38.0919	115.466	$19\frac{1}{4}$	60.4758	291.040
$5\frac{1}{8}$	16.1007	20.6290	$12\frac{1}{4}$	38.4846	117.859	$19\frac{3}{8}$	60.8685	294.832
$5\frac{1}{4}$	16.4934	21.6476	$12\frac{3}{8}$	38.8773	120.277	$19\frac{1}{2}$	61.2612	298.648
$5\frac{3}{8}$	16.8861	22.6907	$12\frac{1}{2}$	39.2700	122.719	$19\frac{5}{8}$	61.6539	302.489
$5\frac{1}{2}$	17.2788	23.7583	$12\frac{5}{8}$	39.6627	125.185	$19\frac{3}{4}$	62.0466	306.355
$5\frac{5}{8}$	17.6715	24.8505	$12\frac{3}{4}$	40.0554	127.677	$19\frac{7}{8}$	62.4393	310.245
$5\frac{3}{4}$	18.0642	25.9673	$12\frac{7}{8}$	40.4481	130.192	20	62.8320	314.160
$5\frac{7}{8}$	18.4569	27.1086	13	40.8408	132.733	$20\frac{1}{8}$	63.2247	318.099

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
20¼	63.6174	322.063	28⅛	88.3575	621.264	36	113.098	1,017.878
20⅜	64.0101	326.051	28¼	88.7502	626.798	36⅛	113.490	1,024.960
20½	64.4028	330.064	28⅜	89.1429	632.357	36¼	113.883	1,032.065
20⅝	64.7955	334.102	28½	89.5356	637.941	36⅜	114.276	1,039.195
20¾	65.1882	338.164	28⅝	89.9283	643.549	36½	114.668	1,046.349
20⅞	65.5809	342.250	28¾	90.3210	649.182	36⅝	115.061	1,053.528
21	65.9736	346.361	28⅞	90.7137	654.840	36¾	115.454	1,060.732
21⅛	66.3663	350.497	29	91.1064	660.521	36⅞	115.846	1,067.960
21¼	66.7590	354.657	29⅛	91.4991	666.228	37	116.239	1,075.213
21⅜	67.1517	358.842	29¼	91.8918	671.959	37⅛	116.632	1,082.490
21½	67.5444	363.051	29⅜	92.2845	677.714	37¼	117.025	1,089.792
21⅝	67.9371	367.285	29½	92.6772	683.494	37⅜	117.417	1,097.118
21¾	68.3298	371.543	29⅝	93.0699	689.299	37½	117.810	1,104.469
21⅞	68.7225	375.826	29¾	93.4626	695.128	37⅝	118.203	1,111.844
22	69.1152	380.134	29⅞	93.8553	700.982	37¾	118.595	1,119.244
22⅛	69.5079	384.466	30	94.2480	706.860	37⅞	118.988	1,126.669
22¼	69.9006	388.822	30⅛	94.6407	712.763	38	119.381	1,134.118
22⅜	70.2933	393.203	30¼	95.0334	718.690	38⅛	119.773	1,141.591
22½	70.6860	397.609	30⅜	95.4261	724.642	38¼	120.166	1,149.089
22⅝	71.0787	402.038	30½	95.8188	730.618	38⅜	120.559	1,156.612
22¾	71.4714	406.494	30⅝	96.2115	736.619	38½	120.952	1,164.159
22⅞	71.8641	410.973	30¾	96.6042	742.645	38⅝	121.344	1,171.731
23	72.2568	415.477	30⅞	96.9969	748.695	38¾	121.737	1,179.327
23⅛	72.6495	420.004	31	97.3896	754.769	38⅞	122.130	1,186.948
23¼	73.0422	424.558	31⅛	97.7823	760.869	39	122.522	1,194.593
23⅜	73.4349	429.135	31¼	98.1750	766.992	39⅛	122.915	1,202.263
23½	73.8276	433.737	31⅜	98.5677	773.140	39¼	123.308	1,209.958
23⅝	74.2203	438.364	31½	98.9604	779.313	39⅜	123.700	1,217.677
23¾	74.6130	443.015	31⅝	99.3531	785.510	39½	124.093	1,225.420
23⅞	75.0057	447.690	31¾	99.7458	791.732	39⅝	124.486	1,233.188
24	75.3984	452.390	31⅞	100.1385	797.979	39¾	124.879	1,240.981
24⅛	75.7911	457.115	32	100.5312	804.250	39⅞	125.271	1,248.798
24¼	76.1838	461.864	32⅛	100.9239	810.545	40	125.664	1,256.640
24⅜	76.5765	466.638	32¼	101.3166	816.865	40⅛	126.057	1,264.510
24½	76.9692	471.436	32⅜	101.7093	823.210	40¼	126.449	1,272.400
24⅝	77.3619	476.259	32½	102.1020	829.579	40⅜	126.842	1,280.310
24¾	77.7546	481.107	32⅝	102.4947	835.972	40½	127.235	1,288.250
24⅞	78.1473	485.979	32¾	102.8874	842.391	40⅝	127.627	1,296.220
25	78.5400	490.875	32⅞	103.280	848.833	40¾	128.020	1,304.210
25⅛	78.9327	495.796	33	103.673	855.301	40⅞	128.413	1,312.220
25¼	79.3254	500.742	33⅛	104.065	861.792	41	128.806	1,320.260
25⅜	79.7181	505.712	33¼	104.458	868.309	41⅛	129.198	1,328.320
25½	80.1108	510.706	33⅜	104.851	874.850	41¼	129.591	1,336.410
25⅝	80.5035	515.726	33½	105.244	881.415	41⅜	129.984	1,344.520
25¾	80.8962	520.769	33⅝	105.636	888.005	41½	130.376	1,352.660
25⅞	81.2889	525.838	33¾	106.029	894.620	41⅝	130.769	1,360.820
26	81.6816	530.930	33⅞	106.422	901.259	41¾	131.162	1,369.000
26⅛	82.0743	536.048	34	106.814	907.922	41⅞	131.554	1,377.210
26¼	82.4670	541.190	34⅛	107.207	914.611	42	131.947	1,385.450
26⅜	82.8597	546.356	34¼	107.600	921.323	42⅛	132.340	1,393.700
26½	83.2524	551.547	34⅜	107.992	928.061	42¼	132.733	1,401.990
26⅝	83.6451	556.763	34½	108.385	934.822	42⅜	133.125	1,410.300
26¾	84.0378	562.003	34⅝	108.778	941.609	42½	133.518	1,418.630
26⅞	84.4305	567.267	34¾	109.171	948.420	42⅝	133.911	1,426.990
27	84.8232	572.557	34⅞	109.563	955.255	42¾	134.303	1,435.370
27⅛	85.2159	577.870	35	109.956	962.115	42⅞	134.696	1,443.770
27¼	85.6086	583.209	35⅛	110.349	969.000	43	135.089	1,452.200
27⅜	86.0013	588.571	35¼	110.741	975.909	43⅛	135.481	1,460.660
27½	86.3940	593.959	35⅜	111.134	982.842	43¼	135.874	1,469.140
27⅝	86.7867	599.371	35½	111.527	989.800	43⅜	136.267	1,477.640
27¾	87.1794	604.807	35⅝	111.919	996.783	43½	136.660	1,486.170
27⅞	87.5721	610.268	35¾	112.312	1,003.790	43⅝	137.052	1,494.730
28	87.9648	615.754	35⅞	112.705	1,010.822	43¾	137.445	1,503.300

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
43⅞	137.838	1,511.910	51¾	162.578	2,103.35	59⅝	187.318	2,792.21
44	138.230	1,520.530	51⅞	162.970	2,113.52	59¾	187.711	2,803.93
44⅛	138.623	1,529.190	52	163.363	2,123.72	59⅞	188.103	2,815.67
44¼	139.016	1,537.860	52⅛	163.756	2,133.94	60	188.496	2,827.44
44⅜	139.408	1,546.56	52¼	164.149	2,144.19	60⅛	188.889	2,839.23
44½	139.801	1,555.29	52⅜	164.541	2,154.46	60¼	189.281	2,851.05
44⅝	140.194	1,564.04	52½	164.934	2,164.76	60⅜	189.674	2,862.89
44¾	140.587	1,572.81	52⅝	165.327	2,175.08	60½	190.067	2,874.76
44⅞	140.979	1,581.61	52¾	165.719	2,185.42	60⅝	190.459	2,886.65
45	141.372	1,590.43	52⅞	166.112	2,195.79	60¾	190.852	2,898.57
45⅛	141.765	1,599.28	53	166.505	2,206.19	60⅞	191.245	2,910.51
45¼	142.157	1,608.16	53⅛	166.897	2,216.61	61	191.638	2,922.47
45⅜	142.550	1,617.05	53¼	167.290	2,227.05	61⅛	192.030	2,934.46
45½	142.943	1,625.97	53⅜	167.683	2,237.52	61¼	192.423	2,946.48
45⅝	143.335	1,634.92	53½	168.076	2,248.01	61⅜	192.816	2,958.52
45¾	143.728	1,643.89	53⅝	168.468	2,258.53	61½	193.208	2,970.58
45⅞	144.121	1,652.89	53¾	168.861	2,269.07	61⅝	193.601	2,982.67
46	144.514	1,661.91	53⅞	169.254	2,279.64	61¾	193.994	2,994.78
46⅛	144.906	1,670.95	54	169.646	2,290.23	61⅞	194.386	3,006.92
46¼	145.299	1,680.02	54⅛	170.039	2,300.84	62	194.779	3,019.08
46⅜	145.692	1,689.11	54¼	170.432	2,311.48	62⅛	195.172	3,031.26
46½	146.084	1,698.23	54⅜	170.824	2,322.15	62¼	195.565	3,043.47
46⅝	146.477	1,707.37	54½	171.217	2,332.83	62⅜	195.957	3,055.71
46¾	146.870	1,716.54	54⅝	171.610	2,343.55	62½	196.350	3,067.97
46⅞	147.262	1,725.73	54¾	172.003	2,354.29	62⅝	196.743	3,080.25
47	147.655	1,734.95	54⅞	172.395	2,365.05	62¾	197.135	3,092.56
47⅛	148.048	1,744.19	55	172.788	2,375.83	62⅞	197.528	3,104.89
47¼	148.441	1,753.45	55⅛	173.181	2,386.65	63	197.921	3,117.25
47⅜	148.833	1,762.74	55¼	173.573	2,397.48	63⅛	198.313	3,129.64
47½	149.226	1,772.06	55⅜	173.966	2,408.34	63¼	198.706	3,142.04
47⅝	149.619	1,781.40	55½	174.359	2,419.23	63⅜	199.099	3,154.47
47¾	150.011	1,790.76	55⅝	174.751	2,430.14	63½	199.492	3,166.93
47⅞	150.404	1,800.15	55¾	175.144	2,441.07	63⅝	199.884	3,179.41
48	150.797	1,809.56	55⅞	175.537	2,452.03	63¾	200.277	3,191.91
48⅛	151.189	1,819.00	56	175.930	2,463.01	63⅞	200.670	3,204.44
48¼	151.582	1,828.46	56⅛	176.322	2,474.02	64	201.062	3,217.00
48⅜	151.975	1,837.95	56¼	176.715	2,485.05	64⅛	201.455	3,229.58
48½	152.368	1,847.46	56⅜	177.108	2,496.11	64¼	201.848	3,242.18
48⅝	152.760	1,856.99	56½	177.500	2,507.19	64⅜	202.240	3,254.81
48¾	153.153	1,866.55	56⅝	177.893	2,518.30	64½	202.633	3,267.46
48⅞	153.546	1,876.14	56¾	178.286	2,529.43	64⅝	203.026	3,280.14
49	153.938	1,885.75	56⅞	178.678	2,540.58	64¾	203.419	3,292.84
49⅛	154.331	1,895.38	57	179.071	2,551.76	64⅞	203.811	3,305.56
49¼	154.724	1,905.04	57⅛	179.464	2,562.97	65	204.204	3,318.31
49⅜	155.116	1,914.72	57¼	179.857	2,574.20	65⅛	204.597	3,331.09
49½	155.509	1,924.43	57⅜	180.249	2,585.45	65¼	204.989	3,343.89
49⅝	155.902	1,934.16	57½	180.642	2,596.73	65⅜	205.382	3,356.71
49¾	156.295	1,943.91	57⅝	181.035	2,608.03	65½	205.775	3,369.56
49⅞	156.687	1,953.69	57¾	181.427	2,619.36	65⅝	206.167	3,382.44
50	157.080	1,963.50	57⅞	181.820	2,630.71	65¾	206.560	3,395.33
50⅛	157.473	1,973.33	58	182.213	2,642.09	65⅞	206.953	3,408.26
50¼	157.865	1,983.18	58⅛	182.605	2,653.49	66	207.346	3,421.20
50⅜	158.258	1,993.06	58¼	182.998	2,664.91	66⅛	207.738	3,434.17
50½	158.651	2,002.97	58⅜	183.391	2,676.36	66¼	208.131	3,447.17
50⅝	159.043	2,012.89	58½	183.784	2,687.84	66⅜	208.524	3,460.19
50¾	159.436	2,022.85	58⅝	184.176	2,699.33	66½	208.916	3,473.24
50⅞	159.829	2,032.82	58¾	184.569	2,710.86	66⅝	209.309	3,486.30
51	160.222	2,042.83	58⅞	184.962	2,722.41	66¾	209.702	3,499.40
51⅛	160.614	2,052.85	59	185.354	2,733.98	66⅞	210.094	3,512.52
51¼	161.007	2,062.90	59⅛	185.747	2,745.57	67	210.487	3,525.66
51⅜	161.400	2,072.98	59¼	186.140	2,757.20	67⅛	210.880	3,538.83
51½	161.792	2,083.08	59⅜	186.532	2,768.84	67¼	211.273	3,552.02
51⅝	162.185	2,093.20	59½	186.925	2,780.51	67⅜	211.665	3,565.24

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
67½	212.058	3,578.48	75⅜	236.798	4,462.16	83¼	261.538	5,443.26
67⅝	212.451	3,591.74	75½	237.191	4,476.98	83⅜	261.931	5,459.62
67¾	212.843	3,605.04	75⅝	237.583	4,491.81	83½	262.324	5,476.01
67⅞	213.236	3,618.35	75¾	237.976	4,506.67	83⅝	262.716	5,492.41
68	213.629	3,631.69	75⅞	238.369	4,521.56	83¾	263.109	5,508.84
68⅛	214.021	3,645.05	76	238.762	4,536.47	83⅞	263.502	5,525.30
68¼	214.414	3,658.44	76⅛	239.154	4,551.41	84	263.894	5,541.78
68⅜	214.807	3,671.86	76¼	239.547	4,566.36	84⅛	264.287	5,558.29
68½	215.200	3,685.29	76⅜	239.940	4,581.35	84¼	264.680	5,574.82
68⅝	215.592	3,698.76	76½	240.332	4,596.36	84⅜	265.072	5,591.37
68¾	215.985	3,712.24	76⅝	240.725	4,611.39	84½	265.465	5,607.95
68⅞	216.378	3,725.75	76¾	241.118	4,626.45	84⅝	265.858	5,624.56
69	216.770	3,739.29	76⅞	241.510	4,641.53	84¾	266.251	5,641.18
69⅛	217.163	3,752.85	77	241.903	4,656.64	84⅞	266.643	5,657.84
69¼	217.556	3,766.43	77⅛	242.296	4,671.77	85	267.036	5,674.51
69⅜	217.948	3,780.04	77¼	242.689	4,686.92	85⅛	267.429	5,691.22
69½	218.341	3,793.68	77⅜	243.081	4,702.10	85¼	267.821	5,707.94
69⅝	218.734	3,807.34	77½	243.474	4,717.31	85⅜	268.214	5,724.69
69¾	219.127	3,821.02	77⅝	243.867	4,732.54	85½	268.607	5,741.47
69⅞	219.519	3,834.73	77¾	244.259	4,747.79	85⅝	268.999	5,758.27
70	219.912	3,848.46	77⅞	244.652	4,763.07	85¾	269.392	5,775.10
70⅛	220.305	3,862.22	78	245.045	4,778.37	85⅞	269.785	5,791.94
70½	220.697	3,876.00	78⅛	245.437	4,793.70	86	270.178	5,808.82
70⅜	221.090	3,889.80	78¼	245.830	4,809.05	86⅛	270.570	5,825.72
70½	221.483	3,903.63	78⅜	246.223	4,824.43	86¼	270.963	5,842.64
70⅝	221.875	3,917.49	78½	246.616	4,839.83	86⅜	271.356	5,859.59
70¾	222.268	3,931.37	78⅝	247.008	4,855.26	86½	271.748	5,876.56
70⅞	222.661	3,945.27	78¾	247.401	4,870.71	86⅝	272.141	5,893.55
71	223.054	3,959.20	78⅞	247.794	4,886.18	86¾	272.534	5,910.58
71⅛	223.446	3,973.15	79	248.186	4,901.68	86⅞	272.926	5,927.62
71¼	223.839	3,987.13	79⅛	248.579	4,917.21	87	273.319	5,944.69
71⅜	224.232	4,001.13	79¼	248.972	4,932.75	87⅛	273.712	5,961.79
71½	224.624	4,015.16	79⅜	249.364	4,948.33	87¼	274.105	5,978.91
71⅝	225.017	4,029.21	79½	249.757	4,963.92	87⅜	274.497	5,996.05
71¾	225.410	4,043.29	79⅝	250.150	4,979.55	87½	274.890	6,013.22
71⅞	225.802	4,057.39	79¾	250.543	4,995.19	87⅝	275.283	6,030.41
72	226.195	4,071.51	79⅞	250.935	5,010.86	87¾	275.675	6,047.63
72⅛	226.588	4,085.66	80	251.328	5,026.56	87⅞	276.068	6,064.87
72¼	226.981	4,099.84	80⅛	251.721	5,042.28	88	276.461	6,082.14
72⅜	227.373	4,114.04	80¼	252.113	5,058.03	88⅛	276.853	6,099.43
72½	227.766	4,128.26	80⅜	252.506	5,073.79	88¼	277.246	6,116.74
72⅝	228.159	4,142.51	80½	252.899	5,089.59	88⅜	277.629	6,134.08
72¾	228.551	4,156.78	80⅝	253.291	5,105.41	88½	278.032	6,151.45
72⅞	228.944	4,171.08	80¾	253.684	5,121.25	88⅝	278.424	6,168.84
73	229.337	4,185.40	80⅞	254.077	5,137.12	88¾	278.817	6,186.25
73⅛	229.729	4,199.74	81	254.470	5,153.01	88⅞	279.210	6,203.69
73¼	230.122	4,214.11	81⅛	254.862	5,168.93	89	279.602	6,221.15
73⅜	230.515	4,228.51	81¼	255.255	5,184.87	89⅛	279.995	6,238.64
73½	230.908	4,242.93	81⅜	255.648	5,200.83	89¼	280.388	6,256.15
73⅝	231.300	4,257.37	81½	256.040	5,216.82	89⅜	280.780	6,273.69
73¾	231.693	4,271.84	81⅝	256.433	5,232.84	89½	281.173	6,291.25
73⅞	232.086	4,286.33	81¾	256.826	5,248.88	89⅝	281.566	6,308.84
74	232.478	4,300.85	81⅞	257.218	5,264.94	89¾	281.959	6,326.45
74⅛	232.871	4,315.39	82	257.611	5,281.03	89⅞	282.351	6,344.08
74¼	233.264	4,329.96	82⅛	258.004	5,297.14	90	282.744	6,361.74
74⅜	233.656	4,344.55	82¼	258.397	5,313.28	90⅛	283.137	6,379.42
74½	234.049	4,359.17	82⅜	258.789	5,329.44	90¼	283.529	6,397.13
74⅝	234.442	4,373.81	82½	259.182	5,345.63	90⅜	283.922	6,414.86
74¾	234.835	4,388.47	82⅝	259.575	5,361.84	90½	284.315	6,432.62
74⅞	235.227	4,403.16	82¾	259.967	5,378.08	90⅝	284.707	6,450.40
75	235.620	4,417.87	82⅞	260.360	5,394.34	90¾	285.100	6,468.21
75⅛	236.013	4,432.61	83	250.753	5,410.62	90⅞	285.493	6,486.04
75¼	236.405	4,447.38	83⅛	261.145	5,426.93	91	285.886	6,503.90

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
91⅛	286.278	6,521.78	94⅛	295.703	6,958.26	97⅛	305.128	7,408.89
91¼	286.671	6,539.68	94¼	296.096	6,976.76	97¼	305.521	7,427.97
91⅜	287.064	6,557.61	94⅜	296.488	6,995.28	97⅜	305.913	7,447.08
91½	287.456	6,575.56	94½	296.881	7,013.82	97½	306.306	7,466.21
91⅝	287.849	6,593.54	94⅝	297.274	7,032.39	97⅝	306.699	7,485.37
91¾	288.242	6,611.55	94¾	297.667	7,050.98	97¾	307.091	7,504.55
91⅞	288.634	6,629.57	94⅞	298.059	7,069.59	97⅞	307.484	7,523.75
92	289.027	6,647.63	95	298.452	7,088.24	98	307.877	7,542.98
92⅛	289.420	6,665.70	95⅛	298.845	7,106.90	98⅛	308.270	7,562.24
92¼	289.813	6,683.80	95¼	299.237	7,125.59	98¼	308.662	7,581.52
92⅜	290.205	6,701.93	95⅜	299.630	7,144.31	98⅜	309.055	7,600.82
92½	290.598	6,720.08	95½	300.023	7,163.04	98½	309.448	7,620.15
92⅝	290.991	6,738.25	95⅝	300.415	7,181.81	98⅝	309.840	7,639.50
92¾	291.383	6,756.45	95¾	300.808	7,200.60	98¾	310.233	7,658.88
92⅞	291.776	6,774.68	95⅞	301.201	7,219.41	98⅞	310.626	7,678.28
93	292.169	6,792.92	96	301.594	7,238.25	99	311.018	7,697.71
93⅛	292.562	6,811.20	96⅛	301.986	7,257.11	99⅛	311.411	7,717.16
93¼	292.954	6,829.49	96¼	302.379	7,275.99	99¼	311.804	7,736.63
93⅜	293.347	6,847.82	96⅜	302.772	7,294.91	99⅜	312.196	7,756.13
93½	293.740	6,866.16	96½	303.164	7,313.84	99½	312.589	7,775.66
93⅝	294.132	6,884.53	96⅝	303.557	7,332.80	99⅝	312.982	7,795.21
93¾	294.525	6,902.93	96¾	303.950	7,351.79	99¾	313.375	7,814.78
93⅞	294.918	6,921.35	96⅞	304.342	7,370.79	99⅞	313.767	7,834.38
94	295.310	6,939.79	97	304.735	7,389.83	100	314.160	7,854.00

The preceding table may be used to determine the diameter when the circumference or area is known. Thus, the diameter of a circle having an area of 7,200 sq. in. is approximately 95¾ in.

A GLOSSARY OF MINING TERMS.

The present glossary is a combination of glossaries of mining terms contained in the following works: Coal and Metal Miners' Pocketbook, Fifth Edition; Raymond's Glossary of Mining and Metallurgical Terms; Powers' Pocketbook for Miners and Metallurgists; Locke's Miners' Pocketbook; Vol. A C, Second Pennsylvania Geological Survey; Ilhseng's Manual of Mining; Chism's Encyclopedia of Mexican Mining Law; a Glossary of Terms as Used in Coal Mining, by W. S. Gresley; 11th Annual Report of the State Mine Inspector of Missouri; Bullman's Colliery Working and Management; Reynolds' Handbook of Mining Laws; Report of the Mine Inspector of Tennessee for 1897; Smithsonian Report for 1886; together with a large number of words which have been added from various stray sources. It is impossible to quote the authority for each definition, as many of the definitions are combinations from a number of authors. Where such different definitions have given distinctly different meanings, each one has been included, but where there has been expressed merely a slight shade of difference, the definition agreeing most closely with current American practice has been taken, or else modified to suit such practice. The foreign words selected are those with which an American is most likely to come in contact, and this portion of the glossary is, of course, not exhaustive. For the large number of purely local terms used in the several coal fields of Great Britain, the reader is referred to Mr. Gresley's glossary.

GLOSSARY.

Abattis (Leicester).—Cross-packing of branches or rough wood, used to keep roads open for ventilation.
Abra (Spanish).—Fissure in a lode, unfilled or only partially filled.
Abronziado (Spanish).—Copper sulphides.
Absolute Pressure.—The pressure reckoned from a vacuum.
Absolute Temperature.—The temperature reckoned from the absolute zero, —459.2° F. or —273° C.
Accompt (Cornish).—Settling day or place.
Achicar (Mexican).—To diminish the quantity of water in any gallery or working, generally by carrying it out in buckets or in leather bags. *Achicadores.*—Laborers employed for said purpose. *Achichinques.*—Same as *Achicadores.* Also applied to hangers-on about police courts, etc. Such people as are generally called strikers in the United States.
Acreage Rent (English).—Royalty or rent for working minerals.
Adarme (Mexican).—A weight for gold, about 1.8 grams.
Addlings (North of England).—Earnings.
Ademador (Spanish).—Mine carpenter, or timberman.
Ademar (Spanish).—To timber.
Adit.—A nearly horizontal passage from the surface, by which a mine is entered and unwatered with just sufficient slope to insure drainage. In the United States, an adit driven across the measures is usually called a tunnel, though the latter, strictly speaking, passes entirely through a hill, and is open at both ends.
Adobe.—Sun-dried brick.
Adventurers.—Original prospectors.
Adverse.—To oppose the granting of a patent to mining claim.
Adze.—A curved cutting instrument for dressing timber.
Aerage (French).—Ventilation.
Aerometers.—The air pistons of a Struve ventilator.
Aerophore.—The name given to an apparatus that will enable a man to enter places in mines filled with explosive or other deadly gases, with safety.
Afinar (Mexican).—Refining gold and silver.
Afterdamp.—The gaseous mixture resulting from an explosion of firedamp.
Agent.—The manager of a mining property.
Agitator.—A mechanical stirrer used in pan amalgamation.
Ahondar (Spanish).—To sink.
Air.—The current of atmospheric air circulating through and ventilating the workings of a mine.
Air Box.—Wooden tubes used to convey air for ventilating headings or sinkings or other local ventilation.
Air Compartment.—An air-tight portion of any shaft, winze, rise, or level, used for improving ventilation.
Air-Course.—See *Airway.*
Air Crossing.—A bridge that carries one air-course over another.
Air Cushion.—A spring caused by confined air.
Air Door.—A door for the regulation of currents of air through the workings of a mine.
Air-End Way (Locke).—Ventilation levels run parallel with main level.
Air Furnace.—A reverberatory furnace in which to smelt lead.
Air Gates (Locke).—(1) Underground roadways, used principally for ventilating purposes. (2) An air regulator.
Air Head (Staff).—Ventilation ways.
Air Heading.—An airway.
Air Hole (Powers).—A hole drilled in advance to improve ventilation by communication with other workings or the surface.
Airless End.—The extremity of a stall in longwall workings in which there is no current of air, or circulation of ventilation, but which is kept pure by diffusion and by the ingress and egress of cars, men, etc.

Air Level.—A level or airway of former workings made use of in subsequent deeper mining operations for ventilating purposes.
Air Oven.—A heated chamber for drying samples of ore, etc.
Air Pipe.—A pipe made of canvas or metal, or a wooden box used in conveying air to the workmen, or for rock drills or air locomotives.
Air-Shaft.—A shaft or pit used expressly for ventilation.
Air Slit (Yorks).—A short head between other air heads.
Air Sollar.—A brattice carried beneath the tram rails or road bed in a heading or gangway.
Air Stack.—A stack or chimney built over a shaft for ventilation.
Airway.—Any passage through which air is carried.
Aitch Piece.—Parts of a pump in which the valves are fixed.
Albanil (Spanish).—Mason.
Albayalde (Spanish).—White lead.
Alberti Furnace.—A continuous reverberatory for mercury ores.
Alcam (Wales).—Tin.
Alive (Cornish).—Productive.
Alloy.—A homogeneous mixture of two or more metals by fusion.
Alluvial Gold.—Gold found associated with water-worn material.
Alluvium.—Gravel, sand, and mud deposited by streams.
Almadeneta (Spanish).—Stamp head.
Almagre (Spanish).—Red ocher.
Alternating Motion.—Up and down, or backward and forward motion.
Alto (Mexican).—The hanging wall of a vein. See *Respaldos.*
Aludel (Spanish).—Earthen condenser for mercury.
Amalgam.—An alloy of quicksilver with some other metal.
Amalgamation.—Absorption of gold and silver by mercury.
Amalgamator.—One that amalgamates gold and silver ores.
Amygdaloidal.—Almond-shaped.
Analysis.—The determination of the original elements and the proportions of each in a substance.
Anemometer.—An instrument used for measuring the velocity of a ventilating current.
Angle Beam.—A two-limbed beam used for turning angles in shafts, etc.
Anhydrous.—Without water in its composition.
Anneal.—To toughen metals, glass, etc. by first heating and then cooling very slowly.
Anthracite.—Coal containing a small percentage of volatile matter.
Anticline.—A flexure or fold in which the rocks on the opposite sides of the fold dip away from each other, like the two legs of the letter A. The inclination on one side may be much greater than on the opposite side. An anticlinal is said to be overturned when the rocks on both sides dip in the same direction.
Anticlinal Axis.—The ridge of a saddle in a mineral vein, or the line along the summit of a vein, from which the vein dips in opposite directions.
Anticlinal Flexure; Anticlinal Fold.—An anticline.
Antiguos, Los (Mexican).—The Spanish or Indian miners of colonial times.
Antimony Star.—The metal antimony when crystallized, showing fern-like markings on the surface.
Aparadores (Mexican).—Persons that rewash or rework tailings from silver mills.
Aparejo (Mexican).—A rigid pair of large stuffed pads connected over back of pack mule by an unpadded portion to protect body of mule when heavy or irregularly shaped loads are carried.
Aperos (Mexican).—All kinds of mining supplies in general. *Aperador.*—A storekeeper.
Apex.—The landing point at the top of a slope or inclined plane, the knuckle; also, the top of an anticlinal. In the U. S. Revised Statutes, the end or edge of a vein nearest the surface.
A pique (Mexican).—Perpendicular.
Apolvillados (Spanish).—Superior ores.
Apron (English).—(1) A covering of timber, stone, or metal, to protect a surface against the action of water flowing over it. (2) A hinged extension to a loading chute.
Aprons.—Stamp-battery copper plates.
Aqua Fortis.—Nitric acid.
Aqua Regia.—A mixture of hydrochloric acid and nitric acid.
Aqueduct.—An artificial elevated way for carrying water.

Arajo (Mexican).—See *Hatajo*.
Arch (Cornish).—Portion of lode left standing to support hanging wall, or because too poor.
Archean.—An early period of geological time.
Arching.—Brickwork or stonework forming the roof of any underground roadway.
Arenaceous.—Sandy; rocks are arenaceous when they contain a considerable percentage of sand.
Arends Tap.—An inverted siphon for drawing molten lead from a crucible or furnace.
Arenillas (Spanish).—Refuse earth.
Argentiferous.—Silver-bearing.
Argillaceous.—Clayey; rocks are argillaceous when they contain a considerable percentage of clay, or have some of the characteristics of clay.
Argol.—Crude tartar deposited from wine.
Arian (Wales).—Silver.
Arm.—The inclined leg of a set of timber.
Arrage (North England).—Sharp corner.
Arrastre.—A circular trough in which drags are pulled round by being connected with a central revolving shaft by an arm and chain. Used for grinding and amalgamating ores. *Arrastre de cuchara*, spoon arrastre; *de marca*, large arrastre; *de mula*, mule-power arrastre.
Arrastrar (Mexican).—To drag along the ground. *Arrastrar el Agua.*—To almost completely exhaust the water in a sump or working.
Arroba (Mexican).—25 lb.
Artesian Well.—An artificial channel of escape, made by a bore hole, for a subterranean stream, subject to hydrostatic pressure.
Ascensional Ventilation.—The arrangement of the ventilating currents in such a manner that the air shall continuously rise until reaching the bottom of the upcast shaft. Particularly applicable to steep seams.
Ashlar.—A facing of cut stone applied to a backing of rubble or rough masonry or brickwork.
Aspirail (French).—Opening for ventilation.
Assay.—The determination of the quality and quantity of any particular substance in a mineral. *Assayer.*—One who performs assays.
Assessment Work.—The annual work necessary to hold a mining claim.
Astel.—Overhead boarding in a gallery.
Astyllen (Cornish).—Small dam in an adit; partition between ore and deads on grass.
Atacador (Mexican).—A tamping bar or tamping stick.
Atecas (Mexican).—Same as *Achicadores*, etc.
Atierres (Spanish).—Refuse rock or dirt inside a mine.
Attle (Cornish).—Refuse rock.
Attle (*Addle*).—The waste of a mine.
Attrition.—The act of wearing away by friction.
Auger Stem.—The iron rod or bar to which the bit is attached in rope drilling.
Auget.—Priming tube.
Aur (Wales).—Gold.
Auriferous.—Gold-bearing.
Ausscharen (German).—Junction of lodes.
Auszimmern (German).—Timbering.
Average Produce (Cornish).—Percentage of fine copper in ore.
Average Standard (Cornish).—Price of pure copper in ore.
Aviador (Spanish).—One who provides the capital to work a mine. *Avio.*—Money furnished to the proprietors of a mine to work the mine, by another person, the *Aviador*. *Avio Contract.*—A contract between two parties for working a mine by which one of the parties, the *aviador*, furnishes the money to the proprietors for working the mine.
Axis.—An imaginary line passing through a body that may be supposed to revolve around it.
Azimuth.—The azimuth of a body is that arc of the horizon that is included between the meridian circle at the given place and a vertical plane passing through the body. It is always measured from due north around to the right.
Azogue (Spanish).—Mercury. *Azogueria.*—Amalgamating works. *Azoguero.* Amalgamator. The person in charge of a patio works. *Azogues.*—Free milling ores.
Azoic.—The age of rocks that were formed before animal life existed.

Back.—(1) A plane or cleavage in coal, etc., having frequently a smooth parting and some sooty coal included in it. (2) The inner end of a heading or gangway. (3) To throw back into the gob or waste the small slack, dirt, etc. (4) To roll large coals out of a waste for loading into cars.
Back Balance.—A self-acting incline in the mine, where a balance car and a carriage in which the mine car is placed are used. The loaded car upon the carriage will hoist the balance car, and the balance car will hoist the carriage and empty car.
Backbye Work.—Work done between the shaft and the working face, in contradistinction to face work, or work done at the face.
Back Casing.—A wall or lining of dry bricks used in sinking through drift deposits, the permanent walling being built up within it. The use of timber cribs and planking serves the same purpose.
Back End (England).—The last portion of a jud.
Backing.—(1) The rough masonry of a wall faced with finer work. (2) Earth deposited behind a retaining wall, etc. (3) Timbers let into notches in the rock across the top of a level.
Backing Deals.—Deal boards or planking placed at the back of curbs for supporting the sides of a shaft that is liable to run.
Back Joint.—Joint plane more or less parallel to the strike of the cleavage, and frequently vertical.
Backlash.—(1) Backward suction of air-currents produced after an explosion of firedamp. (2) Reentry of air into a fan.
Back of Ore.—The ore between two levels which has to be worked from the lower level.
Back Pressure.—The loss, expressed in pounds per square inch, due to getting the steam out of the cylinder after it has done its work.
Back Shift.—Afternoon shift.
Back Skin (North of England).—A leather jacket for wet workings.
Backstay.—A wrought-iron forked bar attached to the back of cars when ascending an inclined plane, which throws them off the rails if the rope or coupling breaks.
Baff Ends.—Long wooden edges for adjusting linings in sinking shafts during the operation of fixing the lining.
Baffle.—To brush out firedamp.
Bait.—Provisions.
Bajo (Mexican).—The footwall of a vein. See *Respaldo.*
Bal (Cornish).—A mine.
Balance.—(1) The counterpoise or weights attached to the drum of a winding engine, to assist the engine in lifting the load out of a shaft bottom and in helping it to slacken speed when the cage reaches the surface. It consists often of a bunch of heavy chains suspended in a shallow shaft, the chains resting on the shaft bottom as unwound off the balance drum attached to the main shaft of the engine. (2) Scales used in chemical analysis and assaying.
Balance Bob.—A large beam or lever attached to the main rods of a Cornish pumping engine, carrying on its outer end a counterpoise.
Balance Box.—A large box placed on one end of a balance bob and filled with old iron, rock, etc. to counterbalance the weight of pump rods.
Balance Brow.—An inclined plane in steep seams on which a platform on wheels travels and carries the cars of coal.
Balance Car.—A small weighted truck mounted upon a short inclined track, and carrying a sheave around which the rope of an endless haulage system passes as it winds off the drum.
Balance Pit.—A pit or shaft in which a balance rises or falls.
Balanzon (Mexican).—The balance bob of a Cornish pump.
Balk.—(1) A more or less sudden thinning out of a seam of coal. (2) Irregular-shaped masses of stone intruding into a coal seam, or bulgings out of the stone roof into the seam. (3) A bar of timber supporting the roof of a mine, or for carrying any heavy load.
Balland (Derbyshire).—Pulverulent lead ore.
Ballast.—Broken stone, gravel, sand, etc. used for keeping railroad ties steady.
Bancos (Spanish).—Horses in a vein or cross-courses.
Band.—A seam or thin stratum of stone or other refuse in a seam of coal.
Bank.—(1) The top of the shaft, or out of the shaft. (2) The surface around the mouth of a shaft. (3) To manipulate coals, etc. on the bank. (4) The whole or sometimes only one side or one end of a working place underground. (5) A large heap of mineral on the surface.

Bank Chain.—A chain that includes the bank of a river or creek.
Bank Claim (Australian).—Mining right on bank of stream.
Banket.—Auriferous conglomerate of South Africa.
Bank Head.—The upper end of an inclined plane, next to the engine or drum, made nearly level.
Bank Right (Australian).—Right to divert water to bank claim.
Banksman.—The man in attendance at the top of the shaft, superintending the work of banking.
Bankwork.—A system of working coal in South Yorkshire.
Bank to Bank.—A shift.
Bannocking.—See *Kirving.*
Bano (Spanish).—Excess of mercury used in torta.
Bar.—A length of timber placed horizontally for supporting the roof. In some cases, bars of wrought iron, about 3 in. × 1 in. × 5 ft. are used.
Bar Diggings.—(1) River placers subject to overflow. (2) Auriferous claims on shallow streams.
Bargain.—Portion of mine worked by a gang on contract.
Barilla (Spanish).—Grains of native copper disseminated through ores.
Baring.—See *Stripping.*
Barmaster (Derbyshire)—Mine manager, agent, and engineer.
Bar Mining.—The mining of river bars, usually between low and high water, although the stream is sometimes deflected and the bar worked below water level.
Barney.—A small car, used on inclined planes and slopes to push the mine car up the slope. *Barney Pit.*—A pit at the bottom of a slope or plane into which the barney runs to allow the mine car to pass over it.
Barra (Mexican).—(1) A bar, as of gold, silver, iron, steel, etc. (2) A certain share in a mine. The ancient Spanish laws, from time immemorial, considered a mine as divided into 24 parts, and each part was called a "barra."
Barra Viuda, or *Aviada* (Mexican).—These are "barras" or shares that participate in the profits, but not in the expenses, of mining concerns. Their share of the expenses is paid by the other shares. Non-assessable shares.
Barranca (Mexican).—A ravine, a gulch. What is improperly called in the United States a canyon or cañon.
Barrel Amalgamation.—Amalgamating ores in revolving barrels.
Barrel Work.—(1) Native copper that can be hand-sorted ready for smelting. (2) Barrel amalgamation.
Barrena (Mexican).—A hand drill for opening holes in rocks for blasting purposes.
Barrenarse (Mexican).—When two mines or two workings (as a shaft or winze, or a gallery) communicate with each other.
Barren Ground.—Strata unproductive of seams of coal, etc. of a workable thickness.
Barreno (Mexican).—(1) A drill hole for blasting purposes. In mechanics, any bored hole. (2) A communication between two mines or two workings.
Barretero (Mexican).—A miner of the first class; one that knows how to point his holes, drill, and blast, or work with a gad.
Barrier Pillar.—A solid block or rib of coal, etc., left unworked between two collieries or mines for security against accidents arising from influx of water.
Barrier System.—The method of working a colliery by pillar and stall, where solid ribs or barriers of coal are left in between a set or series of working places.
Barrow.—(1) A box with two handles at one end and a wheel at the other. (2) Heap of waste stuff raised from a mine; a dump.
Bar Timbering.—A system of supporting a tunnel roof by long top bars, while the whole lower tunnel core is taken out, leaving an open space for the masons to run up the arching. Under certain conditions, the bars are withdrawn after the masonry is completed, otherwise they are bricked in and not drawn.
Base Bullion.—Lead combined with precious metals.
Base Metal.—Metal not classed with the precious metals, gold, silver, platinum, etc., that are not easily oxidized.
Basin.—(1) A coal field having some resemblance in form to a **basin.** (2) The synclinal axis of a seam of coal or stratum of rock
Basket.—A measure of weight = 2 cwt.

Basque.—Crucible or furnace lining.
Bass (Derbyshire).—Indurated clay.
Basset.—Outcrop of a lode or stratum.
Bastard.—A particularly hard massive rock or boulder.
Batch.—An assorted parcel of ore, sometimes called doles, when divided into equal quantities.
Batea.—A shallow wooden bowl used for washing out gold, etc.
Batt (English).—(1) A highly bituminous shale found in the coal measures. (2) Hardened clay, but not fireclay. Same as *Bend* and *Bind.*
Batten.—A piece of thin board less than 12 in. in width.
Batter.—The inclination of a face of masonry or of any inclined portion of a frame or metal structure.
Battery.—(1) A structure built to keep coal from sliding down a chute or breast. (2) An embankment or platform on which miners work. (3) A set of stamps.
Bay.—An open space for waste between two packs in a longwall working. See *Board.*
Bay of Biscay Country.—(Geological).—See *Crab Holes.*
Beach Combing.—Working the sands on a beach for gold, tin, or platinum.
Beans (North of England).—All coal that will pass through about ½″ screen.
Bean Shot.—Copper granulated by pouring into hot water.
Bear.—A deposit of iron at the bottom of a furnace.
Bear; to Bear In.—Underholding or undermining; driving in at the top or at the side of a working.
Bearers.—Pieces of timber 3 or 4 ft. longer than the breadth of a shaft, which are fixed into the solid rock at the sides at certain intervals apart; used as foundations for sets of timber.
Bearing.—(1) The course by a compass. (2) The span or length in the clear between the points of support of a beam, etc. (3) The points of support of a beam, shaft, axle, etc.
Bearing Door.—A door placed for the purpose of directing and regulating the amount of ventilation passing through an entire district of a mine.
Bearing In.—The depth or distance under of the undercut or holing.
Bearing-up Pulley.—A pulley wheel fixed in a frame and arranged to tighten up or take up the slack rope in endless-rope haulage.
Bearing-up Stop.—A partition of brattice or plank that serves to conduct air to a face.
Beat (Cornish).—To cut away a lode.
Beataway.—Working hard ground by means of wedges and sledge hammers.
Bed.—(1) The level surface of a rock upon which a curb or crib is laid. (2) A stratum of coal, ironstone, clay, etc.
Bed Claim (Australian).—A claim that includes the bed of a river or creek.
Bede.—Miners' pickax.
Bedplate.—A large plate of iron used as a foundation for an engine.
Bed Rock.—The solid rock underlying the soil, drift, or alluvial deposits.
Before-Breast.—Rock or vein, which still lies ahead.
Belgian Zinc Furnace.—A furnace for the production of zinc, in which the calcined ore is distilled in tubular retorts.
Bell.—Overhanging rock or slate, of a bell-like form, disconnected from the main roof.
Belland.—A form of lead poisoning to which lead miners are subject.
Belly.—A swelling mass of ore in a lode.
Ben, Benhayl (Cornish).—Productive. The productive portion of a tin stream.
Bench.—(1) A natural terrace marking the outcrop of any stratum. (2) A stratum of coal forming a portion of the vein.
Bench Diggings.—River placers not subject to overflow.
Benching.—To break up with wedges the bottom coals when the holing is done in the middle of the seam.
Benching Up (North of England).—Working on top of coal.
Bench Mark.—A mark cut in a tree or rock whose elevation is known. Used by surveyors for reference in determining elevations.
Bench Working.—The system of working one or more seams or beds of mineral by open working or stripping, in stages or steps.
Bend (Derbyshire).—Indurated clay.
Beneficiar (Mexican).—To treat ores for the purpose of extracting the metallic contents.

Beneficio (Mexican).—Any metallurgical process.
Benheyl (Cornish).—Flowing tin stream.
Bessemer Steel.—Steel made by the Bessemer process.
Beton (English).—Concrete of hydraulic cement with broken stone, bricks, gravel, etc.
Bevel.—The slope formed by trimming away on edge.
Bevel Gear.—A gear-wheel whose teeth are inclined to the axis of the wheel.
Biche.—A hollow-ended tool for recovering boring rods.
Billy Boy.—A boy who attends a Billy Playfair.
Billy Playfair.—A mechanical contrivance for weighing coal, consisting of an iron trough with a sort of hopper bottom, into which all the small coal passing through the screen is conducted and weighed off and emptied from time to time.
Bin.—A box with cover, used for tools, stones, ore, etc.
Bind, or *Binder.*—Indurated argillaceous shales or clay, very commonly forming the roof of a coal seam and frequently containing clay ironstone. See *Batt.*
Binding.—Hiring men.
Bing (North of England).—8 cwt. of ore.
Bing Hole (Derbyshire).—An ore shoot.
Bing Ore (Derbyshire).—Lead ore in lumps.
Bing Tale (North of England).—Ore given to the miner for his labor.
Bit.—A piece of steel placed in the cutting edge of a drill or point of a pick.
Blackband.—Carbonaceous ironstone in beds, mingled with coaly matter sufficient for its own calcination.
Black Batt, or *Black Stone.*—Black carbonaceous shale.
Black Copper.—Impure smelted copper.
Blackdamp.—Carbonic-acid gas.
Black Diamonds.—Coal.
Black Ends.—Refuse coke.
Black Flux.—Charcoal and potassium carbonate.
Black Jack.—(1) Properly speaking, dark varieties of zinc blende, but many miners apply it to any black mineral. (2) Crude black oil used to oil mine cars.
Black Lead.—Graphite.
Black Ore (English).—Partly decomposed pyrites containing copper.
Black Sand.—Dark minerals found with alluvial gold.
Black Stone.—A carbonaceous shale.
Black Tin.—Dressed cassiterite; oxide of tin.
Blanch.—(1) A piece of ore found isolated in the hard rock. (2) Lead ore mixed with other minerals.
Blanched Copper.—Copper alloyed with arsenic.
Blanket Strake (Australian).—Sloping tables or sluices lined with baize, for catching gold.
Blanket Tables.—Inclined planes covered with blankets, to catch the heavier minerals passing over them.
Blast.—(1) The sudden rush of fire, gas, and dust of an explosion through the workings and roadways of a mine. (2) To cut or bring down coal, rocks, etc. by the explosion of gunpowder, dynamite, etc.
Blasting Barrel.—A small pipe used for blasting in wet or gaseous places.
Blast Pipe.—A pipe for supplying air to furnaces.
Blende.—Sulphide of zinc; sphalerite.
Blick (Germany).—Iridescence on gold and silver at end of cupeling.
Blind Coal.—Coal altered by the heat of a trap dike.
Blind Creek.—(1) A creek in which water flows only in very wet weather. (2) (Australasian) Dry watercourse.
Blind Drift.—A horizontal passage in the mine not yet connected with the other workings.
Blind Joint.—Obscure bedding plane.
Blind Lead, or Blind Lode.—A vein having no visible outcrop.
Blind Level.—(1) An incomplete level. (2) A drainage level.
Blind Shaft, or *Blind Pit.*—A shaft not coming to the surface.
Bloat.—A hammer swelled at the eye.
Block Claim (Australian).—A square mining claim.
Block Coal.—Coal that breaks in large rectangular lumps.
Blocking Out.—(1) Working deep leads in blocks; somewhat like horizontal stoping. (2) (Australian) Washing gold gravel in sections.
Block Reefs.—Reefs showing frequent contractions longitudinally.

Block Tin.—Cast tin.

Bloomary.—A forge for making wrought iron.

Blossom.—The decomposed outcrop, float, surface stain, or any indicating traces of a coal bed or mineral deposit. *Blossom Rock.*—(1) Colored veinstone detached from an outcrop. (2) The rock detached from a vein, but which has not been transported.

Blow.—(1) To blast with gunpowder, etc. (2) A dam or stopping is said to blow when gas escapes through it.

Blower.—(1) A sudden emission or outburst of gas in a mine. (2) Any emission of gas from a coal seam similar to that from an ordinary gas burner. (3) A type of centrifugal fan used largely to force air into furnaces. (4) A blowdown ventilating fan.

Blow Fan.—A small centrifugal fan used to force air through canvas pipes or wooden boxes to the workmen.

Blowdown Fan.—A force fan.

Blow In.—To commence a smelting process.

Blown-Out Shot.—A shot that has blown out the tamping, but not broken the coal or rock.

Blow Off.—To let off excess of steam from a boiler.

Blow Out.—(1) To finish a smelting campaign. (2) A blown-out shot. (3) The decomposed mineral exposure of a vein.

Blowpipe.—An instrument for creating a blast whereby the heat of a flame or lamp can be better utilized.

Blue Billy.—Residue of copper pyrites after roasting with salt.

Blue Cap.—The blue halo of ignited gas (firedamp and air) on the top of the flame in a safety lamp, in an explosive mixture.

Blue Elvan (Cornish).—Greenstone.

Blue John.—Fluorspar.

Blue Lead.—A blue-stained stratum of gravel of great extent and richness.

Blue Metal.—A local term for shale possessing a bluish color.

Blue Peach (Cornish).—A slate-blue fine-grained schorl.

Bluestone.—(1) Sulphate of copper. (2) Lapis lazuli. (3) Basalt. (4) Maryland, a gray gneiss; in Ohio, a gray sandstone; in the District of Columbia, a mica schist; in New York, a blue-gray sandstone; in Pennsylvania, a blue-gray sandstone. (5) A popular term among stone men not sufficiently definite to be of value.

Bluff.—Blunt.

Board.—A wide heading usually from 3 to 5 yd. wide.

Board-and-Pillar.— A system of working coal where the first stage of excavation is accomplished with the roof sustained by pillars of coal left between the breasts; often called *Breast-and-Pillar*.

Bob.—An oscillating bell-crank, or lever, through which the motion of an engine is transmitted to the pump rods in an engine or pumping pit. There are ⊥ bobs, L bobs, and V bobs.

Boca or *Boca Mina* (Mexican).—Mouth or mine mouth. This is the name applied to the principal or first opening of a mine, or to the one where the miners are accustomed to descend.

Bochorno (Mexican).—Excessive heat, with want of ventilation, so that the lights go out. See *Vapores*.

Body.—(1) An ore body, or pocket of mineral deposit. (2) The thickness of a lubricating oil or other liquid; also the measure of that thickness expressed in the number of seconds in which a given quantity of the oil at a given temperature flows through a given aperture.

Bog Iron Ore.—Loose earthy brown hematite recently formed in swampy ground.

Boleo (Mexican).—A dump pile for waste rock.

Boliche (Spanish).—Concentrating bowl.

Bollos (Spanish).—Triangular blocks of amalgam.

Bolsa (Spanish).—Small bunch of ore.

Bonanza.—An aggregation of rich ore in a mine.

Bond.—(1) The arrangement of blocks of stone or brickwork to form a firm structure by a judicious overlapping of each other so as to break joint. (2) An agreement for hiring men.

Bone.—Slaty coal or carbonaceous shale found in coal seams.

Bone Ash.—Burnt bones pulverized and sifted.

Bonnet.—(1) The overhead cover of a cage. (2) A cover for the gauze of a safety lamp. (3) A cap piece for an upright timber.

Bonney (Cornish).—An isolated body of ore.

Bonze.—Undressed lead ore.
Booming.—Ground sluicing on a large scale by emptying the contents of a reservoir at once on material collected below, thus removing boulders.
Bord (English).—A narrow breast.
Bord-and-Pillar (English).—See *Pillar-and-Breast.*
Bord Room.—The space excavated in driving a bord. The term is used in connection with the "ridding" of the fallen stone in old bords when driving roads across them in pillar working; thus, "ridding across the old bord room."
Bord Ways Course.—The direction at right angles to the main cleavage planes. In some mining districts, it is termed "on face."
Bore.—To drill.
Bore Hole.—A hole made with a drill, auger, or other tools, in coal, rock, or other material.
Borrasca (Mexican).—The reverse of bonanza. When the mine has a vein, but no ore, it is said to be "en borrasca."
Bort.—Amorphous dark diamond.
Bosh.—The plane in a blast furnace where the greatest diameter is reached.
Boss (English).—(1) An increase of the diameter at any part of the shaft. (2) A person in charge of a piece of work.
Botas (Mexican).—Buckets made of an entire ox skin, to take out water.
Botryoidal.—Grape-like in appearance.
Bottle Jack (English).—An appliance for lifting heavy weights.
Bottom.—(1) The landing at the bottom of the shaft or slope. (2) The lowest point of mining operations. (3) The floor, bottom rock, or stratum underlying a coal bed. (4) In alluvial, the bed rock or reef.
Bottomer, Bottomman.—The person that loads the cages at the pit bottom and gives the signal to bank.
Bottom Joint.—Joint or bedding plane, horizontal or nearly so.
Bottom Lift.—(1) The deepest column of a pump. (2) The lowest or deepest lift or level of a mine.
Bottom Pillars.—Large pillars left around the bottom of a shaft.
Bottoms.—Impure copper alloy below the matte in smelting.
Boulders.—Loose rounded masses of stone detached from the parent rock.
Bounds (Cornish).—A tract of tin ground.
Bout (Derbyshire).—Twenty-four dishes of lead ore.
Bow.—The handle of a kibble.
Bowk.—An iron barrel or tub used for hoisting rock and other débris when sinking a shaft.
Bowke (Staffordshire).—A small wooden box for hauling ironstone underground.
Bowl Metal.—The impure antimony obtained from doubling.
Bowse (Derbyshire).—Lead ore as cut from the lode.
Box.—(1) A 12′ to 14′ section of a sluice. (2) A mine car.
Box Bill.—Tool for recovering boring rods.
Boxing.—A method of securing shafts solely by slabs and wooden pegs.
Brace.—(1) An inclined beam, bar, or strut for sustaining compression or tension. See *Tie-Brace, Sway-Brace.* (2) A platform at the top of a shaft on which miners stand to work the tackle. (3) (Cornish) Building at pit mouth.
Brace Heads.—Wooden handles or bars for raising and rotating the rods when boring a deep hole.
Braize.—Charcoal dust.
Brake Seive.—Hand jigger.
Brances.—Iron pyrites in coal.
Branch.—Small vein shooting off from main lode.
Brashy.—Short and tender.
Brasque.—A mixture of clay and coke or charcoal used for furnace bottoms.
Brass.—(1) Iron pyrites in coal. (2) An alloy of copper and zinc.
Brasses (English).—Fitting of brass in plummer blocks, etc., for diminishing the friction of revolving journals that rest upon them.
Brat.—A thin bed of coal mixed with pyrites or limestone.
Brattice.—A lining or partition.
Brattice Cloth.—Ducking or canvas used for making a brattice.
Brazzil (North of England).—Iron pyrites in coal.
Breaker.—In anthracite mining, the structure in which the coal is broken, sized, and cleaned for market. Known also as *Coal Breaker.*
Breaker Boy.—A boy who works in a coal breaker.

Breakstaff.—The lever for blowing a blacksmiths' bellows, or for working bore rods up and down.
Breakthrough.—A narrow passage cut through a pillar connecting rooms.
Breast.—(1) A stall, board, or room in which coal is mined. (2) The face or wall of a quarry is sometimes called by this name.
Breast-and-Pillar.—A system of working coal by boards or rooms with pillars of coal between them.
Breasting Ore.—The ore taken from the face or end of the tunnel.
Breast Wall (English).—A wall built to prevent the falling of a vertical face cut into the natural soil.
Breccia.—A rock composed of angular fragments cemented together.
Breeding Fire.—See *Gob Fire.*
Breese.—Fine slack.
Breeze.—Small coke, probably same as braize or braise.
Brettis (Derbyshire).—A timber crib filled with slack.
Bridge.—(1) A platform on wheels running on rails for covering the mouth of a shaft or slope. (2) A track or platform passing over an inclined haulageway and which can be raised out of the way of ascending and descending cars. (3) An air crossing.
Bridle Chains.—Short chains by which a cage, car, or gunboat is attached to a winding rope; of use in case the rope pulls out of its socket.
Briquets.—Fuel made of slack or culm and pressed into brick form.
Broaching Bit.—A tool for reopening a bore hole that has been partially closed by swelling of the walls.
Brob.—A spike to prevent timber slipping.
Broil (Cornish).—Traces of a vein in loose matter.
Broken.—A district of coal pillars in process of removal, so called in contradistinction to the first working of a seam by bord-and-wall, or working in the "whole." See *Whole Working.*
Broken Coal.—Anthracite coal that will pass through a mesh or bars $3\frac{1}{4}$ to $4\frac{1}{4}$ in., and over a mesh $2\frac{3}{4}$ in. square. (See page 434.)
Bronce (Mexican).—In mining, copper or iron pyrites.
Brooch (Cornish).—Mixed ores.
Brooching.—Smoothing.
Brood (Cornish).—Heavy waste from tin and copper ores.
Brow.—An underground roadway leading to a working place driven either to the rise or to the dip.
Brown Coal.—Lignite. A fuel classed between peat and bituminous coal.
Brown Spar.—Dolomite containing carbonate of iron.
Brownstone.—(1) Decomposed iron pyrites. (2) Brown sandstone.
Browse.—Imperfectly smelted ore mixed with cinder and clay.
Brujula (Mexican).—A surveyors' (or marine) magnetic compass.
Brush.—(1) To mix air with the gas in a mine working by swinging a jacket, etc., which creates a current. (2) To "*brush*" the roof of an airway, is to take down some of the roof slate, to increase the height or headroom.
Bryle (Cornish).—Traces of a vein in loose matter.
Bucket.—(1) An iron or wooden receptacle for hoisting ore, or for raising rock in shaft sinking. (2) The top valve or clack of a pump.
Bucket Pump.—A lifting pump, consisting of buckets fastened to an endless belt or chain.
Bucket Sword.—A wrought-iron rod to which the pump bucket is attached.
Bucket Tree.—The pipe between the working barrel and the wind bore.
Bucking.—Breaking down ore with a very broad hammer, ready for jigging.
Bucking Hammer.—An iron disk, provided with a handle, used for breaking up minerals by hand.
Buck Quartz.—Hard non-auriferous quartz.
Buck Staff.—Uprights for bracing reverberatory furnaces together.
Buckwheat.—Anthracite coal that will pass through a mesh $\frac{1}{2}$ in. and over a mesh $\frac{1}{4}$ in.
Buddle.—An inclined table, circular or oblong, on which ore is concentrated.
Buddling.—Washing.
Buggy.—A small mine car.
Bug Hole.—A small cavity usually lined with crystals.
Building.—A built-up block or pillar of stone or coal to support the roof.
Buitron (Spanish).—A silver furnace of peculiar form.
Bulkhead.—(1) A tight partition or stopping. (2) The end of a flume carrying water for hydraulicking.

Bulldog.—A refractory furnace lining of calcined mill cinder, containing iron and silica.
Bull Engine.—A single, direct-acting pumping engine, the pump rods forming a continuation of the piston rod.
Buller Shot.—A second shot put in close to, and to do the work not done by, a blown-out shot, loose powder being used.
Bull.—An iron rod used in ramming clay to line a shot hole.
Bulling.—Lining a shot hole with clay.
Bullion.—Uncoined gold and silver.
Bull Pump.—A single-acting pumping engine in which the steam cylinder is placed over the shaft or slope and the pump rods are attached directly to the piston rod. The steam enters below the piston and raises the pump rods; the water is pumped on the down stroke by the weight of the rods.
Bull Pup.—A worthless claim.
Bull Wheel.—A wheel on which the rope carrying the boring rod is coiled when boring by steam machinery.
Bully.—A miners' hammer.
Bumping Table.—A concentrating table with a jolting motion.
Bunch.—A small rich deposit of ore.
Bunding.—A staging in a level for carrying débris.
Bunkers.—Steam coal consumed on board ship.
Bunney.—A nest of ore not lying in a regular vein.
Buntons.—Timbers placed horizontally across a shaft or slope to carry the cage guides, pump rods, column pipe, etc.; also, to strengthen the shaft timbering.
Burden.—(1) Earth overlying a bed of useful mineral. (2) The proportion of ore and flux to fuel in the charge of a blast furnace.
Burr.—Solid rock.
Burrow.—Refuse heap.
Buscones (Spanish).—Prospectors, fossickers, tribute workers.
Bush.—To line a circular hole with a ring of metal, to prevent the hole from wearing out.
Butt.—(1) Coal surface exposed at right angles to the face; the "*ends*" of the coal. (2) The butt of a slate quarry is where the overlying rock comes in contact with an inclined stratum of slate rock.
Butt Entry.—A gallery driven at right angles with the butt joint (see page 285).
Butterfly Valve.—A circular valve that revolves on an axis passing through its center.
Butt Heading.—See *Butt Entry.*
Button.—The globule of metal, the result of an assay.
Button Balance.—A small very delicate balance used for weighing assay buttons.
Butty.—A partner in a contract for driving or mining; a comrade, crony. Sometimes called "*Buddy.*"
By Level.—A side level driven for some unusual but necessary purpose.

Cab.—The side parts of a lode, nearest the walls, which are generally hard and deficient of ore.
Caballo (Mexican).—A "horse" or mass of barren rock in a vein.
Cabezuela (Spanish).—Rich gold and silver concentrates.
Cabin.—(1) A miner's house. (2) A small room in the mine for the use of the officials.
Cable Drilling.—Rope drilling.
Cage.—A platform on which mine cars are raised to the surface.
Cage Guides.—Vertical rods of pine, iron, or steel, or wire rope, fixed in a shaft, between which cages run, and whereby they are prevented from striking one another, or against any portion of the shaft.
Cager.—The person that puts the cars on the cage at the bottom of the shaft.
Cage Seat.—Scaffolding, sometimes fitted with strong springs, to take off the shock, and on which the cage drops when reaching the pit bottom.
Cage Sheets.—Short props or catches on which cages stand during caging or changing cars.
Caking Coal.—Coal that agglomerates on the grate.
Cal.—Wolfram.
Cala (Spanish).—Prospecting pit.
Calcareous.—Containing lime.
Calcine.—To heat a substance; not sufficiently to melt it, but enough to drive off the volatile contents.

Calcining Furnace.—A furnace used for roasting ore in order to drive off certain impurities.
Caliche (Spanish).—Feldspar.
California Pump.—A rude pump made of a wooden box through which an endless belt with floats circulates; used for pumping water from shallow ground.
Callys (Cornish).—Stratified rocks traversed by lodes.
Cam.—(1) A curved arm attached to a revolving shaft for raising stamps. (2) Carbonate of lime and fluorspar, found on the joints of lodes.
Camino (Mexican).—Any gallery, winze, or shaft, inside of a mine used for general transit.
Campaign.—The length of time a furnace remains in blast.
Cañada (Mexican).—See *Barranca*.
Canch, or *Caunche.*—(1) A thickness of stone required to be removed to make height or to improve the gradient of a road. If above a seam, it is termed a "top canch"; if below, a "bottom canch." (2) A trend with sloping sides and very narrow bottom.
Cancha (Spanish).—Space for drying slimes.
Cand (Cornish).—Fluorspar.
Cank (Derbyshire).—Whinstone.
Canker.—The ocherous sediment in coal-pit waters.
Cannel Coal.—See Classification of Coals (page 170).
Cañon (Mexican).—A level, drift, or gallery within a mine. *Cañon de Guia.*—A drift along the vein.
Cants (English).—The pieces forming the ends of buckets of a waterwheel.
Cap.—(1) A piece of plank placed on top of a prop. See, also, *Collar.* (2) The pale bluish elongation of the flame of a lamp caused by the presence of gas.
Capellina (Mexican).—An old-style retort for retorting silver amalgam.
Caple (Cornish).—Hard rock lining tin lodes.
Cap Rock.—The upper rock that covers the bed rock.
Capstan.—A vertical axle used for heavy hoisting, and worked by horizontal arms or bars.
Captain.—Cornish name for manager or boss of a mine.
Car.—Any car used for the conveyance of coal along the gangways or haulage roads of a mine.
Carat.—A weight nearly equal to 4 grains.
Carbon.—A combustible elementary substance forming the largest component part of coal.
Carbona.—(1) A rich bunch of ore in the country rock connected with the lode by a mere thread of mineral. (2) (Cornish) An irregular deposit of tin ore.
Carbonaceous.—Coaly, containing carbon or coal.
Carbonate.—Carbonic acid combined with a base.
Carbonates.—Lead ore. The oxide and carbonic-acid compounds of lead; also applied to lead sulphate.
Carboniferous.—Containing or carrying coal.
Carga (Mexican).—A charge. A mule load, generally of 300 pounds, but variable in different parts of Mexico.
Carriage.—See *Cage* and *Slope Cage.*
Cartridge.—Paper or waterproof cylindrical case filled with gunpowder, forming the charge for blasting.
Cascajo (Mexican).—Gravel.
Case.—A fissure admitting water into a mine.
Case-Harden.—To convert the outer surface of wrought iron into steel by heating it while in contact with charcoal.
Casing.—Tubing inserted in a bore hole to keep out water or to protect the sides from collapsing.
Cast Iron.—Pig iron that contains carbon (up to 5%), silicon, sulphur, phosphorus, etc.
Cata (Spanish).—A mine denounced but not worked.
Catches.—(1) Iron levers or props at the top and bottom of a shaft. (2) Stops fitted on a cage to prevent cars from running off.
Catch Pit.—A reservoir for saving tailings from reduction works.
Cauf (North of England).—A coal bucket or basket.
Cauldron Bottoms.—The fossil remains or the "casts" of the trunks of sigillaria that have remained vertical above or below the seam.
Caulk.—To fill seams or joints with something to prevent leaking.

Caunter, or *Caunter Lode* (Cornish).—A vein running obliquely across the regular veins of the district.
Cave, or *Cave In*.—A caving-in of the roof strata of a mine, sometimes extending to the surface.
Cavils.—Lots drawn by the hewers each quarter year to determine their working places.
Cawk.—Baryta sulphate.
Cazeador (Spanish).—Amalgamator.
Cazo (Mexican).—A vessel for hot amalgamation. Any large copper or iron vessel.
Cebar (Mexican).—(1) To melt rich ores, or lead bullion, etc. in a smelting furnace. (2) To add small quantities of material, from time to time, to the melted mass within a furnace. (3) Generally, to feed any kind of metallurgical machinery or process.
Cement.—(1) Auriferous gravel consolidated together. (2) A finely divided metal obtained by precipitation. (3) A binding material.
Cementation.—The process of converting wrought iron into steel by heating it in contact with charcoal, or of treating cast iron in a bed of hematite ore.
Cendrada (Mexican).—The cupel bottom of a furnace.
Cendradilla (Mexican).—A small reverberatory furnace for smelting rich silver ores in a rough way. Also called *Galeme*.
Center.—A temporary support, serving at the same time as a guide to the masons, placed under an arch during the progress of its construction.
Centrifugal Force.—A force drawing away from the center.
Centripetal Force.—A force drawing toward the center.
CH_4.—Marsh gas (see page 348).
Chain.—A measure 66 or 100 ft. long, divided into 100 links.
Chain-Brow Way.—An underground inclined plane worked on the endless-chain system of haulage.
Chain Pillar.—A pillar left to protect the gangway and air-course, and running parallel to these passages.
Chain Road.—An underground wagonway worked on the endless-chain system of haulage.
Chair.—Sometimes applied to *keeps*.
Chamber.—See *Breast*.
Charco (Mexican).—A pool of water.
Charge.—(1) The amount of powder or other explosive used in one blast or shot. (2) The amount of flux used in assaying. (3) The material fed into a furnace at one time.
Charquear (Mexican).—To dip out water from pools within the mine, throwing it into gutters or pipes that will conduct it to the shaft.
Chats.—(1) The gravel-like tailings derived from the concentration of ores. (2) A low-grade ore, often too poor to handle; the refuse from concentration works. (3) (North of England) Small pieces of stone with ore.
Check-Battery.—A battery to close the lower part of a chute, acting as a check to the flow of coal and as an air stopping.
Checker Coal.—Anthracite coal that seems to be made up of rectangular grains.
Check-Weighman.—A man appointed and paid by the miners to check the weighing of the coal at the surface.
Cheek.—Wall.
Chert.—A silicious rock, often the gangue of lead and zinc.
Chestnut Coal.—Anthracite coal that will pass through a mesh $1\frac{3}{8}$ in. square and over a mesh $\frac{7}{8}$ in. square (see page 434).
Chiflon (Mexican).—A narrow drift directed obliquely downwards. Any pipe from which issues water or air under pressure, or at high velocity.
Chile Bars.—Bars of impure copper, weighing about 200 lb., imported from Chile, corresponding to the Welsh blister copper, containing 98% *Cu*.
Chilian Mill.—A roller mill for crushing ore.
Chill Hardening.—Giving a greater hardness to the outside of cast iron by pouring it into iron molds, which causes the skin of the casting to cool rapidly.
Chimney.—(1) An ore shoot. (2) A furnace or air stack.
Chinese Pump.—Like a California pump, but made entirely of wood.
Chock.—A square pillar for supporting the roof, constructed of prop timber laid up in alternate cross-layers, in log-cabin style, the center being filled with waste.

Chokedamp.—See *Blackdamp.*
Churn Drill.—A long iron bar with a cutting end of steel, used in quarrying, and worked by raising and letting it fall. When worked by blows of a hammer or sledge, it is called a "jumper."
Chute (also spelled *Shute*).—(1) A narrow inclined passage in a mine, down which coal or ore is either pushed or slides by gravity. (2) The loading chute of a tipple.
Chuza (Spanish).—A catch basin for mercury.
Cielo (Mexican.)—A ceiling. *Trabajar de Cielo.*—Overhead stoping.
Cinnabar.—Mercury and sulphur.
Clack.—A valve that is opened and closed by the force of the water.
Clack Door.—The opening into the valve chamber to facilitate repairs and renewals without unseating the pump or breaking the connections.
Clack Piece.—The casting forming the valve chamber.
Clack Seal.—The receptacle for the valve to rest on.
Claggy (North of England).—When coal is tightly joined to the roof.
Claim.—A portion of ground staked out and held by virtue of a miner's right.
Clanny.—A type of safety lamp invented by Dr. Clanny.
Clastic.—Constituted of rocks or minerals that are fragments derived from other rocks.
Clay Course.—A clay seam or gouge found at the sides of some veins.
Claying Bar.—For molding clay in a wet bore hole.
Clay Band.—Argillaceous iron ore; common in many coal measures.
Clean-Up.—Collecting the product of a period of work with battery or sluice.
Clearance.—(1) The distance between the piston at the end of its stroke and the end of the cylinder. (2) The volume or entire space filled with steam at end of a stroke including the space between piston and cylinder head, and the steam ducts to the valve seat.
Cleat.—(1) Vertical cleavage of coal seams, irrespective of dip or strike. (2) A small piece of wood nailed to two planks to keep them together, or nailed to any structure to make a support for something else.
Cleavage.—The property of splitting more readily in some directions than in others.
Clinometer.—An instrument used to measure the angle of dip.
Clod.—Soft and tough shale or slate forming the roof or floor of a coal seam.
Closed Season.—When placers cannot be worked.
Clunch (English).—Under clay, fireclay.
Clutch.—An arrangement at the end of separate shafts by means of which they catch into each other, so that both can revolve together.
Coal Breaker.—See *Breaker.*
Coal Cutter.—A machine for holing or undercutting coal.
Coal Dust.—Very finely powdered coal suspended in the airways of a mine.
Coal Measures.—Strata of coal with the attendant rocks.
Coal Pipes (North of England).—Very thin irregular coal beds.
Coal Road.—An underground roadway or heading in coal.
Coal Smut.—See *Blossom.*
Coaly Rashings.—Soft dark shale, in small pieces, containing much carbonaceous matter.
Coarse (*Coose*).—When lode stuff is not rich, the ore being only thinly disseminated throughout it.
Coarse Metal.—In copper smelting, the compound containing the copper concentrated in it after the first smelting to get rid of the bulk of the gangue in the ore.
Coaster.—One that picks ore from the dump.
Cob (Cornish).—To break up ore for sorting.
Cobbing Hammer.—A short double-ended hammer for breaking minerals to sizes.
Cobre.—Cuban copper ores.
Cockermeg, or *Cockers.*—Timber used to hold coal face while it is being undercut.
Cockle (Cornish).—Black tourmaline, often mistaken for tin.
Cod (North of England).—The bearing of an axle.
Cofer (Derbyshire).—To calk a shaft by ramming clay behind the lining.
Coffer.—Mortar box of a battery.
Coffer Dam.—An enclosure built in the water, and then pumped dry, so as to permit masonry or other work to be carried on inside of it.
Coffin (Cornish).—An old pit.

Cog.—A chock.
Cohete (Mexican).—A rocket; applied to a blast within a mine or outside.
Coil Drag.—A tool for picking pebbles, etc. from drill holes.
Coke.—The fixed carbon and ash of coal sintered together.
Colas (Spanish).—Tailings from a stamp mill or any wet process.
Collar.—(1) A flat ring surrounding anything closely. (2) Collar of a shaft is the first wood frame of a shaft. (3) The bar or crosspiece of a framing in entry timbering.
Colliery.—The whole plant, including the mine and all adjuncts.
Colliery Warnings (English).—Telegraphic messages sent from signal-service stations to the principal colliery centers to warn managers of mines when sudden falls of the barometer occur.
Colorados (Spanish).—Decomposed ores stained with iron.
Colores (Mexican).—Metal-stained ground or rocks.
Colrake.—A shovel for stirring lead ores while washing.
Color.—Minute traces or individual specks of gold.
Column, or Column Pipe.—The pipe conveying the drainage water from the mine to the surface.
Comer (Mexican).—To eat. *Comerse los Pilares.*—To take out the last vestiges of mineral from the sides and rock pillars of a mine.
Conchoidal.—Shell-like, such as the curved fracture of flint.
Concrete.—Artificial stone, formed by mixing broken stone, gravel, etc. with lime, cement, tar, or other binder. When hydraulic cement is used instead of lime, the mixture is called *beton* (English).
Concretion.—A cemented aggregation of one or more kinds of minerals around a nucleus.
Conduit.—(1) A covered waterway. (2) An airway.
Conduit Hole.—A flat hole drilled for blasting up a thin piece in the bottom of a level.
Conductors (English).—See *Guides*.
Conformable.—Strata are conformable when they lie one over the other with the same dip.
Conglomerate.—The rock formation underlying the *Coal Measures;* a rock containing or consisting of pebbles, or of fragments of other rocks cemented together; English *Pudding Rock* or millstone grit.
Conical Drum.—The rope roll or drum of a winding engine, constructed in the form of two truncated cones placed back to back, the outer ends being usually the smaller in diameter.
Consumido (Mexican).—The amount of mercury that disappears by chemical combination during the treatment of ore by any amalgamation process.
Contact.—Union of different formations.
Contact Load or Vein.—A vein lying between two differently constituted rocks.
Contour.—(1) The line that bounds the figure of an object. (2) In surveying, a contour line is a line every point of which is at an equal elevation.
Contramina (Mexican).—Countermine. Any communication between two or more mines. Also, a tunnel communicating with a shaft.
Cope (Derbyshire).—Lead mining on contract.
Cope, or *Coup.*—An exchange of working places between hewers.
Copelilla (Spanish).—Zinc-blende.
Copella (Spanish).—Dry amalgam.
Copper Plate.—A sheet of copper that, when coated with mercury, is used in amalgamation.
Corbond.—An irregular mass from a lode.
Cord.—A cord weighs about 8 tons.
Cores.—Cylinder-shaped pieces of rock produced by the diamond-drill system of boring.
Corf.—A mine wagon or tub.
Cornish Pumps.—A single-acting pump, in which the motion is transmitted through a walking beam; in other respects similar to a *Bull Pump.*
Coro-Coro (South American).—Grains of native copper mixed with pyrite, chalcopyrite, mispickel, etc.
Cortar Pillar (Mexican).—To form a rock support or pillar within a mine, at the opening of a cross-cut or elsewhere.
Cortar Sogas (Mexican).—Literally, to cut the ropes. To abandon the mine, taking away everything useful or movable.
Corve.—A mining wagon or tub.

Costean (Cornish).—To prospect a lode by sinking pits on its supposed course.
Costeaning.—Trenching for a lode.
Cost Book (Cornish).—Mining accounts.
Cotton Rock.—(1) Decomposed chert. (2) A variety of earthy limestone.
Coulee.—(1) A solified stream or sheet of lava extending down a volcano, often forming a ridge or spur. (2) A deep gulch or water channel, usually dry.
Counter.—(1) A cross-vein. (2) (English) An apparatus for recording the number of strokes made by the Cornish pumping engine. (3) A secondary haulageway in a coal mine.
Counterchute.—A chute down which coal is dumped to a lower level or gangway.
Countergangway.—A level or gangway driven at a higher level than the main one.
Country.—The formation traversed by a lode.
Country Rock.—The main rock of the region through which the veins cut, or that surrounding the veins.
Course.—The direction of a line in regard to the points of compass.
Coursing or *Coursing the Air.*—Conducting it through the different portions of a mine by means of doors, stoppings, and brattices.
Cow.—A self-acting brake.
Coyoting.—Irregular mining by small pits.
Crab.—A variety of windlass or capstan consisting of a short shaft or axle, either horizontal or vertical, which serves as a rope drum for raising weights; it may be worked by a winch or handspikes.
Crab Holes.—Holes often met with in the bed rock of alluvial. Also depressions on the surface owing to unequal disintegration of the underlying rock.
Cradle.—A box with a sieve mounted on rockers for washing auriferous alluvial.
Cradle Dump.—A rocking tipple for dumping cars. See *Dump*.
Cramp (English).—(1) A short bar of metal having its two ends bent downwards at right angles for insertion into two adjoining pieces of stone, wood, etc. to hold them together. (2) A pillar left for support in a mine.
Cranch.—Part of a vein left by previous workers.
Crane (English).—A hoisting machine consisting of a revolving vertical post or stalk, a projecting jib, and a stay for sustaining the outer end of the jib; these do not change their relative positions as they do in a derrick. There is also a rope drum with winding rope, etc.
Creaze (Cornish).—(1) Tin ore collected in the middle of the buddle. (2) The middle of a buddle.
Creep.—The gradual upheaval of the floor or sagging of the roof of mine workings due to the weighting action of the roof and a tender floor.
Creston (Mexican).—The outcrop or apex of a vein or mineral deposit.
Crevice.—A fissure.
Crevicing.—Picking out the gold caught in cracks and crevices in the rocks over which it has been washed.
Criadero (Mexican).—(1) A mineral deposit of irregular form, not vein-like. (2) A chamber in a vein filled with ore of more or less richness. (3) Any mineral deposit. This latter is the more modern sense, and the word is so used in the mining laws at present in force in Mexico.
Crib.—(1) A structure composed of horizontal timbers laid on one another, or a framework built like a log cabin. See *Chock*. (2) A miner's luncheon. (3) See *Curb*.
Cribbing.—Close timbering, as the lining of a shaft, or the construction of cribs of timber, or timber and earth or rock to support a roof.
Cribble.—A sieve.
Crisol (Mexican).—A crucible of any kind.
Crop.—See *Outcrop*.
Crop Fall.—A caving in of the surface at or near the outcrop of a bed of coal.
Cropping Coal.—The leaving of a small thickness of coal at the bottom of the seam in a working place, usually in order to keep back water. The coal so left is termed "*Cropper Coal.*"
Croppings.—Portions of a vein as seen exposed at the surface.
Cropping Out.—Appearing at the surface; outcropping.
Cross-Course.—A vein lying more or less at right angles to the regular vein of the district.

Crosscut.—(1) A tunnel driven through or across the measures from one seam to another. (2) A small passageway driven at right angles to the main gangway to connect it with a parallel gangway or air-course.
Crosses and Holes (Derbyshire).—Made in the ground by the discoverer of a lode to temporarily secure possession.
Cross-Heading.—A passage driven for ventilation from the airway to the gangway, or from one breast through the pillar to the adjoining working.
Cross-Heading, or *Cross-Gateway.*—A road kept through goaf and cutting off the gateways at right angles or diagonally.
Cross-Hole.—See *Crosscut* (2).
Cross-Latches.—See *Latches.*
Cross-Spur.—A vein of quartz that crosses the reef.
Cross-Vein.—An intersecting vein.
Crouan (Cornish).—Granite.
Crowbar.—A strong iron bar with a slightly curved and flattened end.
Crowfoot.—A tool for drawing broken boring rods.
Crown Tree.—A piece of timber set on props to support the roof.
Crucero (Mexican).—A crosscut for ventilation to get around a horse, or to prospect for the vein.
Crucible.—(1) The bottom of a cupola furnace in which the molten materials collect. (2) Pots for smelting assays in.
Crush.—See *Squeeze, Thrust.*
Crusher.—A machine used for crushing ores and rock.
Crushing.—Reduction of mineral in size by machinery.
Crystal.—A solid of definite geometrical form, which mineral (or sometimes organic) matter has assumed.
Culm.—Anthracite-coal dirt.
Culm Bank, or *Culm Dump.*—Heaps of culm now generally kept separate from the rock and slate dumps.
Cuña (Mexican).—Literally, a wedge. A short drill or picker generally known in the United States as a "gad."
Cupel.—A cup made of bone ash for absorbing litharge.
Curb.—(1) A timber frame intended as a support or foundation for the lining of a shaft. (2) The heavy frame or sill at the top of a shaft.
Curbing.—The wooden lining of a shaft.
Cut.—(1) To strike or reach a vein. (2) To excavate in the side of a hill.
Cutter.—A term employed in speaking of any coal-cutting or rock-cutting machines; the men operating them, or the men engaged in underholing by pick or drill.
Cutting Down.—To cut down a shaft is to increase its sectional area.

Dam.—A timber bulkhead, or a masonry or brick stopping built to prevent the water in old workings from flooding other workings, or to confine the water in a mine flooded to drown out a mine fire.
Damp.—Mine gases and gaseous mixtures are called damps. See also *Afterdamp, Blackdamp, Firedamp, Stinkdamp.*
Dan (North of England).—A truck without wheels.
Danger Board.—See *Fireboard.*
Dant (North of England).—Soft inferior coal.
Datum Water Level.—The level at which water is first struck in a shaft sunk on a reef or gutter.
Davy.—A safety lamp invented by Sir Humphrey Davy.
Day.—Light seen at the top of a shaft.
Day Fall.—See *Crop Fall.*
Day Shift.—The relay of men working in the daytime.
Dead.—The air of a mine is said to be dead or heavy when it contains carbonic-acid gas, or when the ventilation is sluggish.
Dead.—(1) Unproductive. (2) Unventilated.
Dead Men's Graves (Australian).—Grave-like mounds in the basalt underlying auriferous gravels.
Dead Quartz.—Quartz carrying no mineral.
Dead Riches.—Lead carrying much bullion.
Dead Roast.—To completely drive off all volatile substances.
Deads.—Waste or rubbish from a mine.
Dead Work.—Exploratory or prospecting work that is not directly productive. Brushing roof, lifting bottom, cleaning up falls, blowing rock, etc.
Dean (Cornish).—The end of a level.
Débris.—Fragments from any kind of disintegration.

Deep (English).—"To the deep," toward the lower portion of a mine; hence, the lower workings.
Delta.—A triangularly shaped piece of alluvial land at the mouth of the river.
Demasia (Mexican).—A piece of unoccupied ground between two mining concessions.
Denudation.—The laying bare by water or other agency.
Denuncio (Mexican).—Denouncement. The act of applying for a mining concession under the old mining laws.
Deposit.—(1) Irregular ore bodies not veins. (2) A bed or any sedimentary formation.
Deputy (English).—(1) A man who fixes and withdraws the timber supporting the roof of a mine, and attends to the safety of the roof and sides, builds stoppings, puts up bratticing, and looks after the safety of the hewers, etc. (2) An underground official who sees to the general safety of a certain number of stalls or of a district, but does not set the timber himself, although he has to see that it is properly and sufficiently done. (3) (American) A deputy sheriff.
Derrick.—(1) A crane in which the rope or chain forming the stay can be let out or hauled in at pleasure, thus altering the inclination of the jib. (2) The structure erected to sink a drill hole and the framework above shafts are sometimes called by this name.
Derrumbe, or *Derrumbamineto* (Mexican).—The caving in of the whole or a portion of a mine.
Desaguador (Spanish).—A water pipe or drain.
Desague (Mexican).—Drainage of a mine by any means.
Descargar (Mexican).—Literally, "to unload." *Descargar un Horno.*—To tear down a furnace.
Descubridora (Mexican).—The first mine opened in a new district or on a new mineral deposit.
Desecho (Spanish).—Foul red mercury.
Desfrute (Mexican).—Taking out ore. *Obras de Desfrute.*—Stopes, etc.
Desmontar (Mexican).—Literally, to clear away underbrush. In mining, to take away useless and barren rocks; to remove rubbish.
Desmontes (Spanish).—Poor ores.
Despensa (Mexican).—(1) A pantry or storeroom. (2) A secure room to lock up rich ore.
Despoblado (Spanish).—Ore with much gangue.
Despoblar (Mexican).—To suspend work in a mine.
Dessue (Cornish).—To cut away the ground beside a thin vein so as to remove the latter whole.
Destajo (Mexican).—(1) A contract to do any kind of work in or about a mine or elsewhere for a fixed price. (2) Piece work, as distinguished from time work. *Destajero.*—A contractor for piece work.
Detaching Hook.—A self-acting mechanical contrivance for setting free a winding rope from a cage when the latter is raised beyond a certain point in the head-gear; the rope being released, the cage remains suspended in the frame.
Devil's Dice.—Cubes of limonite, pseudomorphs after pyrites.
Diagonal Joints.—Joints diagonal to the strike of the cleavage.
Dial (English).—An instrument similar to a surveyor's compass, with vernier attached.
Dialing.—Surveying.
Die.—The bottom iron block of a battery, or grinding pan on which the shoe acts.
Digging.—Mining operations in coal or other minerals.
Diggings.—Where gold and other minerals are dug out from shallow alluvials.
Dike.—See also *Dyke.*
Dillies, or *Ginneys.*—Short self-acting inclines where one or two tubs at a time are run.
Dillueing (Cornish).—Dressing tin slimes in a fine sieve.
Dip.—(1) To slope downwards. (2) The inclination of strata with a horizontal plane. (3) The lower workings of a mine.
Dip Joint.—Vertical joints about parallel to the direction of the cleavage dip.
Dippa (Cornish).—A small catch-water pit.
Dipping Needle.—A magnetic needle suspended in a vertical plane; for locating iron deposits.

Dirt Fault.—A confusion in a seam of coal, the top and bottom of the seam being well defined, but the body of the vein being soft and dirty.
Dish (Cornish).—An ore measure; in lead mines, a trough 28 in. long, 4 in. deep, and 6 in. broad; sometimes 1 gallon, sometimes 14 to 16 pints.
Disintegration.—Separation by mechanical means, not by decomposition.
Ditch.—(1) The drainage gutter in a mine. (2) A drainage gutter on the surface. (3) An open conveyor of water for hydraulic or irrigation purposes.
Divide.—The top of a ridge, hill, or mountain.
Dividing Slate.—A stratum of slate separating two benches of coal. See *Parting.*
Divining, or *Dowsing*, *Rod.*—A small forked hazel twig that, when held loosely in the hands, is supposed to dip downwards when passing over water or metallic minerals.
Dizzue (Cornish).—See *Dessue.*
Dog.—(1) An iron bar, spiked at the ends, with which timbers are held together or steadied. (2) A short heavy iron bar, used as a drag behind a car or trip of cars when ascending a slope to prevent their running back down the slope in case of accident. See *Drag.*
Dog Hole.—A little opening from one place in a mine to another, smaller than a breakthrough.
Dog Iron.—A short bar of iron with both ends pointed and bent down so as to hold together two pieces of wood into which the points are driven. Or one end may be bent down and pointed, while the other is formed into an eye, so that if the point be driven into a log, the other end may be used to haul on.
Doles.—Small piles of assorted or concentrated ore.
Dolly.—(1) A machine for breaking up minerals, being a rough pestle and mortar, the former being attached to a spring pole by a rope. (2) A tool used to sharpen drills.
Dolly Tub (Cornish).—A tub in which ore is washed, being agitated by a dolly or perforated boards.
Donk (North of England).—Soft mineral found in cross-veins.
Donkey Engine (English).—(1) A small steam engine attached to a large one, and fed from the same boiler; used for pumping water into the boiler. (2) A small steam engine.
Door Piece (English).—The portion of a lift of pumps in which the clack or valve is situated.
Doors.—Wooden doors in underground roads or airways to deflect the air-current.
Door Tender.—A boy whose duty it is to open and close a mine door before and after the passage of a train of mine cars.
Dope.—An absorbent for holding a thick liquid. The material that absorbs the nitroglycerine in explosives.
Double Shift.—When there are two sets of men at work, one set relieving the other.
Double Tape Fuse.—Fuse of superior quality, or having a heavier and stronger covering.
Double Timber.—Two props with a bar placed across the tops of them to support the roof and sides.
Downcast.—The opening through which the fresh air is drawn or forced into the mine; the intake.
Dradge (Cornish).—(1) Inferior ore separated from the prill. (2) Pulverized refuse.
Draftage.—A deduction made from the gross weight of ore when transported, to allow for loss.
Drag.—(1) The frictional resistance offered to a current of air in a mine. (2) See *Dog.*
Draw.—(1) To "draw" the pillars; robbing the pillars after the breasts are exhausted. (2) An effect of creep upon the pillars of a mine.
Draw a Charge.—To take a charge from a furnace.
Drawlift.—A pump that receives its water by suction and will not force it above its head.
Draw-Hole.—An aperture in a battery through which the coal is drawn.
Drawing an Entry.—Removing the last of the coal from an entry.
Drawn.—The condition in which an entry or room is left after all the coal has been removed. See *Robbed.*
Dresser (Staffordshire).—A large coal pick.

Dressing.—Preparing poor or mixed ores mechanically for metallurgical operations.
Dressing Floors.—The floors or places where ores are dressed.
Drift.—(1) A horizontal passage underground. A drift follows the vein, as distinguished from a crosscut, which intersects it, or a level or gallery, which may do either. (2) In coal mining, a gangway above water level, driven from the surface in the seam. (3) Unstratified diluvium.
Drifting.—Winning pay dirt from the ground by means of drives.
Drill.—An instrument used in boring holes.
Drive (*Drift*). A horizontal passage in a lode.
Drive.—To cut an opening through strata.
Driving.—Excavating horizontal passages, in contradistinction to sinking or raising.
Driving on Line.—Keeping a heading or breast accurately on a given course by means of a compass or transit.
Dropper.—(1) A spur dropping into the lode. (2) A feeder. (3) A branch leaving the vein on the footwall side. (4) Water dropping from the roof.
Drop Shaft.—A monkey shaft down which earth and other matter are lowered by means of a drop (i. e., a kind of pulley with break attached); the empty bucket is brought up as the full one is lowered.
Druggon (Staffordshire).—A vessel for carrying fresh water into a mine.
Drum.—The cylinder or pulley on which the winding ropes are coiled or wound.
Drum Rings.—Cast-iron rings with projections to which are bolted the laggings forming the surface for the ropes to lap on.
Drummy.—Sounding loose, open, shaky, or dangerous when tested.
Druse.—A hollow cavity lined with small crystals.
Dry Amalgamation.—Treating ores with hot, dry mercury.
Dry Diggings.—Placers never subject to overflow.
Dry Ore.—Argentiferous ores that do not contain enough lead for smelting purposes.
Duck Machine.—An arrangement of two boxes, one working within the other, for forcing air into mines.
Duelas (Mexican).—Staves of a barrel or cask, etc.
Dumb'd.—Choked, of a sieve or grating.
Dumb Drift.—A short tunnel or passage connecting the main return airways of a mine with the upcast shaft some distance above the furnace, in order to prevent the return air laden with mine gases from passing through or over the ventilating furnace.
Dump.—(1) A pile or heap of ore, coal, culm, slate, or rock. (2) The tipple by which the cars are dumped. (3) To unload a car by tipping it up. (4) The pile of mullock as discharged from a mine.
Dumper.—A car so constructed that the body may be revolved to dump the material in front or on either side of the track.
Durn (Cornish).—A timber frame.
Durr (German).—Barren ground.
Dust.—See *Coal Dust.*
Dust Gold.—Pieces under 2 to 3 dwt.
Duty.—The unit of measure of the work of a pumping engine expressed in foot-pounds of work obtained from a bushel, or 100 lb., or other unit of fuel.
Dyke, or *Dike.*—(1) A wall of igneous rock passing through strata, with or without accompanying dislocation of the strata. (2) A fissure filled with igneous matter. (3) Barren rock.
Dzhu (Cornish).—See *Dessue.*

Ear.—The inlet or intake of a fan.
Echadero (Mexican).—A level place near a mine where ore is cleaned, piled, weighed, and loaded on mules or other conveyance. Also called *patio* of the mine.
Echado (Mexican).—The dip of the vein.
Edge Coals (English).—Highly inclined seams of coal, or those having a dip greater than 30°.
Efflorescence.—An incrustation by a secondary mineral, due to loss of water of crystallization.
Efydd (Wales).—Copper.
Egg Coal.—Anthracite coal that will pass through a 2¾″ square mesh and over a 2″ square mesh (see page 434).

Elbow.—A sharp bend, as in a lode or pipe.
Electric Blast.—Instantaneous blasting of rock by means of electricity.
Elevator Pump.—An endless band with buckets attached, running over two drums for draining shallow ground.
Elvan.—A Cornish name applied to most dike rocks of that county, irrespective of the mineral constitution, but in the present day restricted to quartz porphyries.
Emborrascarse (Mexican).—To go barren by the vein terminating or pinching out, etc.
Empties.—Empty mine or railroad cars.
Encino (Mexican).—Live oak.
End Joint (End Cleat).—A joint or cleat in a seam about at right angles to the principal or face cleats.
Endless Chain.—A system of haulage or pumping by the moving of an endless chain.
Endless Rope.—A system of haulage same as endless chain, except that a wire rope is used instead of chain.
End, or *End-On.*—Working a seam of coal at right angles to the principal or face cleats.
Engine Plane.—An incline up which loaded cars are drawn by a rope operated by an engine located at the top or bottom of the incline. The empty cars descend by gravity, pulling the rope after them.
Engineer.—(1) One who has charge of the surveying or machinery about a mine. (2) One who runs an engine.
Ensayes (Mexican).—Assays.
Entibar (Mexican).—To timber a mine or any part thereof.
Entry.—A main haulage road, gangway, or airway. An underground passage used for haulage or ventilation, or as a manway.
Entry Stumps.—Pillars of coal left in the mouths of abandoned rooms to support the road, entry, or gangway till the entry pillars are drawn.
Erosion.—The wearing away of rocks by rains, etc.
Escaleras (Mexican).—Ladders, generally made of notched sticks.
Escarpment.—A nearly vertical natural face of rock or soil.
Escoria (Mexican).—Slag or cinders.
Escorial.—Slag pile.
Escorificador (Mexican).—A scorifier, in assaying.
Espejuelo (Mexican).—A mineral gangue, with a faintly reflecting surface.
Espeton (Mexican).—The tapping bar of a smelting furnace.
Estano (Spanish).—Tin.
Estrujon (Mexican).—A second collection of amalgam, generally very pasty.
Exploder.—A chemical employed for the instantaneous explosion of powder.
Exploitation.—The working of a mine, and similar undertakings; the examination instituted for that purpose.
Exploration.—Development.
Explosion.—Sudden ignition of a body of firedamp.
Eye (English).—(1) A circular hole in a bar for receiving a pin and for other purposes. (2) The eye of a shaft is the very beginning of a pit. (3) The eye of a fan is the central or intake opening.

Face.—(1) The place at which the material is actually being worked, either in a breast or heading or in longwall. (2) The end of a drift or tunnel.
Face-On.—When the face of the breast or entry is parallel to the face cleats of the seam (see page 285).
Face Wall.—A wall built to sustain a face cut into the natural earth, in distinction to a retaining wall, which supports earth deposited behind it.
Faenas (Mexican).—Dead work, in the way of development.
Fahlband (German).—A course impregnated with metallic sulphides.
Faiscador (Spanish).—A gold washer.
Fall.—(1) A mass of roof or side which has fallen in any part of a mine. (2) To blast or wedge down coal.
False Bedding.—Irregular lamination, wherein the laminæ, though for short distances parallel to each other, are oblique to the general stratification of the mass at varying angles and directions.
False Bottom.—(1) A movable bottom in some apparatus. (2) A stratum on which pay dirt lies, but which has other layers below it.
False Cleavage.—A secondary slip cleavage superinduced on slaty cleavage.
False Set.—A temporary set of timber used until work is far enough advanced to put in a permanent set.

Famp (North of England).—Thin beds of soft tough shale.
Fan.—A machine for creating a circulation of air in a mine.
Fan Drift.—A short tunnel or conduit leading from the top of the air-shaft to the fan.
Fanega (Mexican).—A Spanish measure of about 2½ bushels.
Fang (Derbyshire).—An air-course.
Fascines (English).—Bunches of twigs and small branches for forming foundations on soft ground.
Fast.—(1) A road driven in a seam with the solid coal at each side. "Fast at an end," or "fast at one side," implies that one side is solid coal and the other open to the goaf or some previous excavation. (2) Bed rock.
Fast End.—An end of a breast of coal that requires cutting.
Fat Coals.—Those containing volatile oily matters.
Fathom (English).—6 ft.
Fault.—A fracture or disturbance of the strata breaking the continuity of the formation.
Feather.—A slightly projecting narrow rib lengthwise on a shaft, arranged to catch into a corresponding groove in anything that surrounds and slides along the shaft.
Feather Edge.—(1) A passage from false to true bottom. (2) The thin end of a wedge-shaped piece of rock or coal.
Feather Ore.—Sulphide of lead and antimony.
Feed.—Forward motion imparted to the cutters or drills of rock-drilling or coal-cutting machinery, either hand or automatic.
Feeder.—(1) A runner of water. (2) A small blower of gas.
Feigh (North of England).—Ore refuse.
Fencing.—Fencing in a claim is to make a drive round the boundaries of an alluvial claim, to prevent wash dirt from being worked out by adjoining claim holders.
Fend-Off (English).—A sort of bell-crank for turning a pump rod past the angle of a crooked shaft.
Fierros (Mexican).—Iron matte.
Fiery.—Containing explosive gas.
Fines.—Very small material produced in breaking up large lumps.
Fire.—(1) A miners' term for firedamp. (2) To blast with gunpowder or other explosive. (3) A word shouted by miners to warn one another when a shot is fired.
Fire-Bars (English).—The iron bars of a grate on which the fuel rests.
Fireboard.—A piece of board with the word *fire* painted upon it and suspended to a prop, etc., in the workings, to caution men not to take a naked light beyond it, or to pass it without the consent of the foreman or his assistants.
Fire Boss.—An underground official who examines the mine for gas and inspects safety lamps taken into the mine.
Fireclay.—Any clay that will withstand a great heat without vitrifying.
Firedamp.—(1) A mixture of light carburetted hydrogen (CH_4) and air in explosive proportions; often applied to CH_4 alone or to any explosive mixture of mine gases.
Fireman.—See *Fire Boss.*
Fire-Setting.—The process of exposing very hard rock to intense heat, rendering it thereby easier for breaking down.
First Working.—See *Whole Working.*
Firsts.—The best ore picked from a mine.
Fish.—To join two beams, rails, etc. together by long pieces at their sides.
Fissure.—An extensive crack.
Fissure Vein.—Any mineralized crevice in the rock of very great depth.
Flags.—Broad flat stones for paving.
Flagstone.—Any kind of a stone that separates naturally into thin tabular plates suitable for pavements and curbing. Especially applicable to sandstone and schists.
Flang (Cornish).—A double-pointed pick.
Flange (English).—A projecting ledge or rim.
Flat.—(1) A district or set of workings separated by faults, old workings, or barriers of solid coal. (2) The siding or station laid with two or more lines of railway, to which the putters bring the full cars from the working face, and where they get the empty cars to take back. (3) The area of working places, from which coal is brought to the same station, is also called "flat."

Flat Rod.—A horizontal rod for conveying power to a distance.
Flats.—Narrow decomposed parts of limestones that are mineralized.
Flat Sheet.—Sheet-iron flooring at landings and in the plats, chambers, and junctions of drives, to facilitate the turning and management of trucks.
Flat Wall (Cornish).—Foot-wall.
Flintshire Furnace.—A kind of reverberatory furnace used for smelting lead ores.
Float.—Broken and transported particles or boulders of vein matter.
Float Gold.—Gold in thin scales, which floats on water.
Float Ore.—A term applied by miners to ore found loose in the clay or soil.
Float Stones.—Loose boulders from lodes lying on or near the surface.
Flood Gate (English).—A gate to let off excess of water in flood or other times.
Floor.—(1) The stratum of rock upon which a seam of coal immediately lies. (2) That part of a mine upon which you walk or upon which the road bed is laid.
Floram (Cornish).—Very fine tin.
Flour Gold.—The finest alluvial gold.
Flouring.—Mercury reduced to fine globules that are easily contaminated and will not amalgamate.
Flucan.—A soft, greasy, clayey substance found in the joints of veins.
Fluke.—A rod for cleaning out drill holes.
Flume.—An artificial watercourse.
Fluming—Lifting a river out of its bed with wooden launders or pipes, in order to get at the bed for working.
Flush.—(1) To clean out a line of pipes, gutters, etc. by letting in a sudden rush of water. (2) The splitting of the edges of stone under pressure. (3) Forming an even continuous line or surface. (4) To fill a mine with fine material.
Fluthwerk (German).—River prospecting.
Flux.—Iron ore, limestone, and sand, which are added in various proportions to the charge in a furnace to make the gangue melt up and flow off easily.
Fodder (North of England).—21 cwt. of lead.
Following Stone.—Roof stone that falls on the removal of the seam.
Foot (Cornish).—2 gallons, or 60 lb., black tin.
Foot-Hole.—Holes cut in the sides of shafts or winzes to enable miners to ascend and descend.
Foot-Piece.—(1) A wedge of wood or part of a slab placed on the foot-wall against which a stull piece is jammed. (2) A piece of wood placed on the floor of a drive to support a leg or prop of timber.
Foot-Wall.—The lower boundary of a lode.
Footway.—Ladders in mines.
Force Fan.—See *Blowdown Fan.*
Force Piece.—Diagonal timbering to secure the ground.
Force Pump.—A pump that forces water above its valves.
Forebay.—Penstock. The reservoir from which water passes directly to a waterwheel.
Forepoling.—Driving the poles over the timbers so that their ends project beyond the last set of timber, so as to protect the miner from roof falls; used also in quicksand or other loose material.
Forewinning.—The first working of a seam in distinction from pillar drawing.
Fork.—(1) A deep receptacle in the rock, to enable a pump to extract the bottom water. A pump is said to be "going in fork" when the water is so low that air is sucked through the windbore. (2) (Cornish) Bottom of sump. (3) (Derbyshire) Prop for soft ground.
Formation.—A series of strata that belong to a single geological age.
Fossickers (Australian).—Grubbers for gold in the beach sand.
Fossicking.—Overhauling old workings and refuse heaps for gold.
Fossil.—Organic remains or impressions of them found in mineral matter.
Fother (North of England).—$\frac{1}{3}$ chaldron.
Frame.—A table composed of boards, slightly inclined, over which water runs to wash off waste from sluice tin.
Frame Set.—The legs and cap or collar arranged so as to support a passage mined out of the rock or lode; also called *Framing.*
Free.—Coal is said to be "free" when it is loose and easily mined, or when it will "run" without mining.
Free Milling.—Ores requiring no roasting or chemical treatment.

Free Miner.—Licensed miner.
Fresno (Mexican).—An ash tree.
Fronton (Mexican).—Any working face.
Fuelle (Mexican).—A bellows.
Furnace.—A large coal fire at or near the bottom of an upcast shaft, for producing a current of air for ventilating the mine.
Furnace Shaft.—The upcast shaft in furnace ventilation.
Fuse.—(1) A hollow tube filled with an explosive mixture for igniting cartridges. (2) To melt.

Gabarro (Mexican).—Ore in large pieces, from egg size up.
Gad.—A small steel wedge used for loosening jointy ground.
Gal (Cornish).—Hard gossan.
Galapago (Mexican).—A turtle-shaped pig of lead.
Gale.—A grant of mining ground.
Galemador (Spanish).—A silver furnace.
Galeme (Mexican).—A reverberatory furnace. See *Cendradilla.*
Galera (Mexican).—A shed; any long or large room; a storehouse.
Galiage.—Royalty.
Gallery.—A horizontal passage.
Gallos (Mexican).—Rich specimens of silver or gold ore, particularly those that show native silver or gold.
Gallows Frame.—The frame supporting a pulley over which the hoisting rope passes to the engine.
Gambucino (Mexican).—A prospector for gold placers or ores.
Gang.—A set of miners, a "shift."
Gangue.—Waste material from lodes.
Gangway.—The main haulage road or level.
Ganister.—A hard, compact, extremely silicious fireclay.
Garabata (Mexican).—A curved iron bar used in copper smelting.
Gas.—See *Firedamp.* Any firedamp mixture in a mine is called *gas.*
Gas Coal.—Bituminous coal containing a large percentage of gas.
Gash Vein.—A wedge-shaped vein.
Gasket.—A band or ring of any material put between the flanges of pipes before bolting, to make them water-tight or steam-tight.
Gatches (Cornish).—Final sludge from tin dressing.
Gate.—An underground road connecting a stall or breast with a main road.
Gateway.—(1) A road kept through goaf in longwall working. (2) A gangway having ventilating doors.
Gauge Door.—A wooden door fixed in an airway for regulating the supply of ventilation necessary for a certain district or number of men.
Gauge Pressure.—The pressure shown by an ordinary steam gauge. It is the pressure above that of the atmosphere.
Gears, or *Pair of Gears.*—(1) Two props and a plank, the plank being supported by the props at either end. (2) The teeth of a gear-wheel or pinion.
Geodes.—Large nodules of stone with a hollow in the center.
Geordie.—A safety lamp invented by George Stephenson.
Geyser.—Natural fountain of hot water and steam.
Gib.—(1) A short prop of timber by which coal is supported while being holed or undercut. (2) A piece of metal often used in the same hole with a wedge-shaped key for holding pieces together.
Ginneys.—See *Dillies.*
Gin, or *Horse Gin.*—A vertical drum and framework by which the minerals and dirt are raised from a shallow pit.
Giraffe.—A mechanical appliance for receiving and tipping a car full of ore or waste rock when it arrives at the surface.
Girdle.—A thin bed or band of stone. A roof is described as a post roof with metal girdles, or a metal roof with post girdles, according as the post or the metal predominates.
Glist (Cornish).—Micaceous iron ore.
Goaf, or *Goave.*—That part of a mine from which the coal has been worked away, and the space more or less filled up with waste.
Gob.—(1) Another word for *Goaf.* (2) To leave coal and other minerals that are not marketable in the mine. (3) To stow or pack any useless underground roadway with rubbish.
Gob Fire.—Spontaneous combustion underground of fine coal and slack in the gob.

Gobbing Up.—Filling with waste.
Gob Road.—A roadway in a mine carried through the goaf.
Going Headways, or *Going Bord.*—A headway or bord laid with rails, and used for conveying the coal tubs to and from the face.
Golpeador (Mexican).—A striker, in hand drilling.
Gossan.—A spongy ferruginous oxide, left after the soluble substances have been dissolved out of a lode.
Goths (Staffordshire).—Sudden burstings of coal from the face, owing to tension caused by unequal pressure.
Gouge.—The layer of clay, or decomposed rock, that lies along the wall or walls of a vein. It is not always valueless.
Grade.—The amount of fall or inclination in ditches, flumes, roads, etc.
Grain.—An obscure vertical cleavage usually more or less parallel to the end or dip joints.
Granza (Mexican).—Metallic minerals from the size of rice to that of hens' eggs.
Grasa (Mexican).—Literally, grease. Slags.
Grass.—The surface of the ground.
Grassero (Spanish).—Slag heap.
Grate Coal.—See *Broken Coal.*
Grating.—A perforated iron sheet or wire gauze placed in front of reducing machinery.
Gravel.—Water-worn stones about the size of marbles.
Gray Metal.—Shale of a grayish color.
Graywacke.—A compact gray sandstone frequently found in Paleozoic formations.
Greenstone.—A general term employed to designate green-colored igneous rocks, as diorite, dolerite, diabase, gabbro, etc.
Grena (Spanish).—Undressed ore.
Greta (Mexican).—Impure litharge formed in a reverberatory furnace.
Griddle.—A coarse sieve used for sifting ores, clay, etc.
Grizzly.—A grating to throw out large stones from hydraulic gold sluices.
Ground Rent.—Rent paid for surface occupied by the plant, etc. of a colliery.
Groundsill.—A log laid on the floor of a drive on which the legs of a set of timber rest.
Ground Sluicing.—Washing alluvial, loosened by pick and shovel, in trenches cut out of the bed rock, using bars of rock as natural riffles. Used in shallow placers, hill claims, bank claims, and stream diggings.
Grout (English).—Thin mortar poured into the interstices between stones and bricks.
Grove (Derbyshire).—A mine.
Grub Stake.—The mining outfit or supplies furnished to a prospector on condition of sharing in his finds.
Grueso (Mexican).—Lump ore.
Grundy.—Granulated pig iron.
Guag (Cornish).—Worked-out ground.
Gualdria (Mexican).—A long and stout beam, generally sustaining other beams or some heavy weight.
Guano.—A brown, gray, or white, light powdery deposit, consisting mainly of the excrement of sea fowl in rainless tracts, or of bats in caves.
Guarda Raya (Mexican).—A landmark; a monument.
Guardas (Mexican).—The country seat immediately enclosing any metalliferous vein or deposit.
Gubbin.—Ironstone.
Guia (Mexican).—Indications where to cut a pay streak or to find a vein.
Guides.—See *Cage Guides.*
Guija (Spanish).—Quartz.
Guijo (Mexican).—A pointed pivot, upon which turns the upright center piece of an arrastre, of a door, etc.
Gunboat.—A self-dumping car, holding from 5 to 8 tons of coal, used upon inclined planes or slopes. They are filled by emptying the mine cars into them at the foot of the slope.
Gunnies (Cornish).—3 ft.
Gurt (Cornish).—Water runnel from dressing floor.
Gutter.—(1) A small water-draining channel. (2) The lowest part of a lead that contains the most highly auriferous dirt.

Hacienda de Beneficio (Mexican).—In mining, a metallurgical works; any metallurgical works, usually an amalgamation works.

Hacienda de Fundicion (Mexican).—A smelting works.

Hacienda de Maquila (Mexican).—A custom mill.

Hade.—The inclination of a vein or fault, taking the vertical as zero.

Haiarn (Wales).—Iron.

Half Course.—(1) At an angle of 45° from general or previous course. (2) Half on the level and half on the dip.

Half Set.—One leg piece and a cap.

Halvans.—Gangue containing a little ore.

Hammer-and-Plate.—A signaling apparatus.

Hand Barrow.—A long box with handles at each end.

Hand Dog.—A kind of spanner or wrench for screwing up and disconnecting the joints of boring rods at the surface.

Handspike.—A wooden lever for working a capstan or windlass.

Handwhip.—An apparatus used in shallow alluvial workings, consisting of an upright, at the top of which is balanced a long sapling; at the thick end of the sapling, a bag of earth is fastened to counterbalance the bucket of dirt to be raised at the other end.

Hanger-On.—The man that runs the loaded cars on to the cages and gives the signal to hoist. See *Cager.*

Hanging Spear Rod.—Wooden pump rods adjustable by screws, etc. by which a sinking set of pumps is suspended in a shaft.

Hanging Wall.—In metalliferous mining, the stratum lying geologically directly above a bed or vein.

Hardhead.—Residue from tin refining; contains much iron and arsenic.

Harrow.—Somewhat like an agricultural harrow; it is fixed to the pole of a puddling machine and dragged around to break up and mix the auriferous clays with water.

Hatajo (Mexican).—A drove of pack mules.

Hat Rollers.—Cast-iron or steel rollers shaped like a hat, revolving on a vertical pin, for guiding inclined haulage ropes around curves.

Hatter.—A miner working by himself on his own account.

Haulage Clip.—Levers, jaws, wedges, etc. by which cars, singly or in trains, are connected to the hauling ropes.

Hauling.—The drawing or conveying of the product of the mine from the working places to the bottom of the hoisting shaft, or slope.

Haunches.—The parts of an arch from the keystone to the skew back.

Hazle (North of England).—Sandstone mixed with shale.

Head.—(1) Pressure of water in pounds per square inch. (2) Any subterranean passage driven in solid coal. (3) That part of a face nearest the roof.

Head, or Sluice Head (Australia and New Zealand).—A supply of 1 cu. ft. of water per second, regardless of the head, pressure, or size of orifice.

Head-Block.—(1) A stop at the head of a slope or shaft to stop cars from going down the shaft or slope. (2) A cap piece.

Headboard.—A wedge of wood placed against the hanging wall, and against which one end of the stull piece is jammed.

Header.—(1) A rock that heads off or delays progress. (2) A blast hole at or above the head. (3) A stone or brick laid lengthwise at right angles to the face of the masonry. (4) The Stanley Header is an entry boring machine that bores the entire section of the entry in one operation.

Head-Gear.—The pulley frame erected over a shaft.

Head-House.—When the head-frame is housed in, the structure is known by this name.

Heading.—(1) A continuous passage for air or for use as a manway; a gangway or entry. (2) A connecting passage between two rooms, breasts, or other working places.

Head-Piece.—A cap; a collar.

Headrace.—An aqueduct for bringing a supply of water on to the ground.

Headstocks.—Gallows frame; head-frame.

Headways.—(1) A road; usually 9 ft. wide, in a direction parallel to the main-cleavage planes of the coal seams, which direction is called "headways course," and is generally about north and south in the Newcastle coal field. It is termed "on end" in other districts. (2) Cross-headings.

Heave.—The shifting of rocks, seams, or lodes on the face of a cross-course, etc.

Heaving.—The rising of the thill (or floor) of a seam where the coal has been removed.
Hechado (Spanish).—Dip.
Heel of Coal.—A small body of coal left under a larger body as a support.
Heel of a Shot.—In blasting, the front of a shot, or the face of the shot farthest from the charge.
Heep Stead (English).—The entire surface plant of a colliery.
Helper.—A miner's assistant, who works under the direction of the miner.
Helve.—A handle.
Hewer.—A collier that cuts coal; a digger.
High Reef.—The bed rock or reef is frequently found to rise more abruptly on one side of a gutter than on the other, and this abrupt reef is termed a high reef.
Hijuelas (Mexican).—Literally, little children. A small-sized torta made up as a sort of assay on a large scale, with from 1 to 5 kilograms of argentiferous mud.
Hill Diggings.—Placers on hills.
Hilo (Spanish).—A thin metalliferous vein.
Hitch.—(1) A fault or dislocation of less throw than the thickness of the seam in which it occurs. (2) Step cut in the rock or lode for holding stay-beams, beams, or timber, etc. for various purposes.
Hoarding.—A temporary close fence of boards placed around a work in progress.
Hogback.—A roll occurring in the floor and not in the roof, the coal being cut out or nearly so, for a distance.
Hoister.—A machine used in hoisting the product. It may be operated by steampower or horsepower.
Hole.—(1) To undercut a seam of coal by hand or machine. (2) A bore hole. (3) To make a communication from one part of a mine to another.
Holing.—(1) The portion of the seam or underclay removed from beneath the coal before it is broken down. (2) A short passage connecting two roads. (3) See *Kirving.*
Holing Through.—Driving a passage through to make connection with another part of the same workings, or with those in an adjacent mine.
Hood.—See *Bonnet.*
Hopper.—A coal pocket; a funnel-shaped feeding trough.
Horn.—A piece of bullock's horn about 8 in. in length, cut boat-shaped, for concentrating by water on a small scale.
Horn Coal.—Coal worked partly end-on and partly face-on.
Horn Silver.—Chloride of silver.
Horse Gin.—A gearing for winding by horsepower.
Horsepower.—The power that will raise 33,000 lb. 1 ft. high per minute.
Horse, or *Horsebacks.*—(1) Natural channels cut or washed away by water in a coal seam, and filled up with shale and sandstone. Sometimes a bank or ridge of foreign matter in a coal seam. (2) A mass of country rock lying within a vein or bed. (3) Any irregularity cutting out a portion of the vein. See *Dirt Fault* and *Rock Fault.*
Horse Whim.—A vertical drum worked by a horse, for hauling or hoisting. Called also *Horse Gin.*
Hose.—A strong flexible pipe made of leather, canvas, rubber, etc., and used for the conveyance of water, steam, or air under pressure to any particular point.
H *Piece.*—The portion of a column pipe containing the valves of the pump.
Hueco (Mexican).—See *Demasia.*
Hulk (Cornish).—To pick out the soft portions of a lode.
Hundido (Mexican).—See *Derrumbe.*
Hungry.—Worthless looking.
Hurdy Gurdy.—A waterwheel that receives motion from the force of traveling water.
Hushing.—Prospecting by laying ground bare by sudden discharges of pent-up water.
Hutch (Cornish).—(1) An ore-washing box. (2) (English) A mine car.
Hydraulic Cement.—A mixture of lime, magnesia, alumina, and silica that solidifies beneath water.
Hydraulicking.—Working auriferous gravel beds by hydraulic power.
Hydrocarbons.—Compounds of hydrogen and carbon.

Igneous Rocks.—Those that have been in a more or less fused state.
Inbye.—In a direction inward toward the face of the workings, or away from the entrance.
Incline.—Short for inclined plane. Any inclined heading or slope road or track having a general inclination or grade in one direction.
Incorporo (Mexican).—The act of adding and mixing the mercury and other ingredients in and to the metalliferous mud for the patio process of amalgamation. *Incorporadero.*—Place where the incorporo is effected.
Indicator.—(1) A mechanical contrivance attached to winding, hauling, or other machinery, which shows the position of the cages in the shaft or the cars on an incline during its journey or run. (2) An apparatus for showing the presence of firedamp in mines, the temperature of goaves, the speed of a ventilator, pressure of steam, air, or water, etc.
Indicator Card, or *Diagram.*—A diagram showing the variation of steam pressure in the cylinder of an engine during an entire stroke or revolution.
Indoor Catches.—Strong beams in Cornish pumping-engine houses to catch the beam in case of a smash, thus preventing damage to the engine itself.
In-fork.—When a pump continues working after water has receded below the holes of the wind bore.
Ingot.—A lump of cast metal.
In Place.—A vein or deposit in its original position.
Insalmoro (Mexican).—The addition of salt to the torta or mud heap.
Inset.—The entrance to a mine at the bottom, or part way down a shaft where the cages are loaded.
Inside Slope.—A slope on which coal is raised from a lower to a higher gangway.
Inspector.—A government official whose duties are to enforce the laws regulating the working of mines.
Instroke.—The right to take coal from a royalty to the surface by a shaft in an adjoining royalty. A rent is usually charged for this privilege.
Intake.—(1) The passage through which the fresh air is drawn or forced in a mine, commencing at the bottom of a downcast shaft, or the mouth of a slope. (2) The fresh air passing into a colliery.
Inversion.—Such a change in the dip of a vein or seam as makes the foot-wall or floor the upper and the hanging wall or roof the lower of the two.
Irestone (Cornish).—Any hard tough stone.
Iron Hat.—Decomposed ferruginous mineral capping a lode.
Iron Man.—A coal-cutting machine.

Jaboncillo (Mexican).—Decomposed talcose rock or hardened clay, generally found in a vein, and sometimes indicating the proximity of a rich strike.
Jacal (Mexican).—See *Xacal.*
Jack.—A lantern-shaped case made of tin, in which safety lamps are carried in strong currents of air.
Jacket.—(1) An extra surface covering, as a steam jacket. (2) A water-jacket is a furnace having double iron walls, between which water circulates.
Jack-Lamp.—A Davy lamp, with the addition of a glass cylinder outside the gauze.
Jacotinga (Brazilian).—Ferruginous ores associated with gold.
Jales (Spanish).—Tailings.
Jales-Jalsontles (Mexican).—Rich tailings or middlings from concentration or amalgamation.
Jars.—In rope drilling, two long links which take up the shock of impact when the falling tools strike the bottom of the hole.
Jenkin.—A road cut in a pillar of coal in a bordways direction, that is, at right angles to the main-cleavage planes.
Jig.—(1) A self-acting incline. (2) A machine for separating ores or minerals from worthless rock by means of their difference in specific gravity; also called *Jigger* or *Washer.*
Jigger.—(1) A kind of coupling hook for connecting cars on an incline. (2) An allowance of liquor sometimes issued to workmen (almost obsolete). (3) See *Jig.*
Jigging.—Separating heavy from light particles by agitation in water.

Jockey.—A self-acting apparatus carried on the front truck of a set for releasing it from the hauling rope.
Joggle.—A joint of trusses or sets of timber for receiving pressure at right angles, or nearly so.
Joints.—(1) Divisional planes that divide the rock in a quarry into natural blocks. There are usually two or three nearly parallel series, called by quarrymen end joints, back joints, and bottom joints, according to their position. (2) In coal seams, the less pronounced cleats or vertical cleavages in the coal. The shorter cleats, about at right angles to the face cleats and the bedding plane of the coal.
Jud.—(1) A portion of the working face loosened by "kirving" underneath, and "nicking" up one side. The operation of kirving and nicking is spoken of as "making a jud." (2) The term jud is also applied to a working place, usually 6 to 8 yd. wide, driven in a pillar of coal. When a jud has been driven the distance required, the timber and rails are removed, and this is termed "drawing a jud."
Judge (Derbyshire and North of England).—A measuring staff.
Jugglers, or *Jugulars.*—Timbers set obliquely against the rib in a breast, to form a triangular passage to be used as a manway, airway, or chute.
Jump.—An upthrow or a downthrow fault.
Jumper.—A hand drill used in boring holes in rock for blasting.

Kann (Cornish).—Fluorspar.
Kazen (Cornish).—A sieve.
Keckle-Meckle.—Poorest lead ore.
Keeker.—An official that superintends the screening and cleaning of the coal.
Keel Wedge.—A long iron wedge for driving over the top of a pick hilt.
Keeps, or *Keps.*—Wings, catches, or rests to hold the cage at rest when it reaches any landing.
Keeve.—A large wooden tub used for the final concentration of tin oxide.
Kenner.—Time for quitting work.
Kerf.—The undercut made to assist the breaking of the coal.
Kerned (Cornish).—Pyrites hardened by exposure.
Kerve (North of England).—In coal mining, to cut under.
Kevil (Derbyshire).—Calcspar found in lead veins.
Key.—(1) An iron bar of suitable size and taper for filling the keyways of shaft and pulley so as to keep both together. (2) A kind of spanner used in deep boring by hand.
Kibble.—See *Bowk.* Often made with a bow or handle, and carrying over a ton of débris.
Kickup.—An apparatus for emptying trucks.
Kieve.—Tossing tub.
Killas (Cornish).—Clay slate.
Kiln.—A chamber built of stone or brick, or sunk in the ground, for burning minerals in.
Kind.—(1) Tender, soft, easy. (2) Likely looking stone.
Kind-Chaudron.—A system of sinking shafts through water-bearing strata.
Kirving (North of England).—The cutting made beneath the coal seam.
Kist.—The wooden box or chest in which the deputy keeps his tools. The chest is always placed at the flat or lamp station, and this spot is often referred to by the expression "at the kist."
Kit.—Any workman's necessary outfit, as tools, etc.
Kitty.—A squib made of a straw tube filled with powder.
Knee Piece.—A bent piece of piping.
Knocker.—A lever that strikes on a plate of iron at the mouth of a shaft, by means of which miners below can signal to those on the top.
Knocker Line.—The signal line extending down the shaft from the knocker.
Koepe System.—A system of hoisting without using drums, the rope being endless and passing over pulleys instead of around a drum.

Labor (Mexican).—Mine workings in general. Specifically, a stope or any other place where ore is being taken out.
Ladderway, *Ladder Road.*—The particular shaft, or compartment of a shaft, used for ladders.
Lagging.—(1) Small round timbers, slabs, or plank, driven in behind the legs and over the collar, to prevent pieces of the sides or roof from falling through. (2) Long pieces of timber closely fitted together and fastened to the drum rings to form a surface for the rope to wind on.

Lamas (Spanish).—(1) Slimes. (2) Argentiferous mud treated by amalgamation.
Lamero (Mexican).—Place of deposit for lamas.
Laminæ.—Sheets not naturally separated, but which may be forced apart.
Lampazo (Mexican).—A sort of broom formed of green branches on the end of a long stick, to dampen the flame in a reverberatory furnace.
Lamp Men.—Cleaners, repairers, and those having charge of the safety lamps at a colliery.
Lamp Stations.—Certain fixed stations in a mine at which safety lamps are allowed to be opened and relighted by men appointed for that purpose, or beyond which, on no pretense, is a naked light allowed to be taken.
Lander.—The man that receives a load of ore at the mouth of a shaft.
Lander's Crook.—A hook or tongs for upsetting the bucket of hoisted rock.
Landing.—(1) A level stage for loading or unloading a cage or skip. (2) The top or bottom of a slope, shaft, or inclined plane.
Land Sale.—The sale of coal loaded into carts or wagons for local consumption.
Land-Sale Collieries.—Those selling the entire product for local consumption, and shipping none by rail or water.
Lap.—One coil of rope on a drum or pulley.
Lappior (Cornish).—An ore dresser.
Large.—The largest lumps of coal sent to the surface, or all coal that is hand picked or does not pass over screens; also, the large coal that passes over screens.
Larry.—(1) A car to which an endless rope is attached, fixed at the inside end of the road, forming part of the appliance for taking up slack rope. See *Balance Car.* (2) See *Barney.* (3) A car with a hopper bottom and adjustable chutes for feeding coke ovens. (4) A hopper-shaped car for charging coke ovens.
Latches.—(1) A synonym of switch. Applied to the split rail and hinged switches. (2) Hinged switch points, or short pieces of rail that form rail crossings.
Lateral.—From the side.
Lath.—A plank laid over a framed center or used in poling.
Launder.—Water trough.
Laundry Box.—The box at the surface receiving the water pumped up from below.
Lava.—A common term for all rock matter that has flowed from a volcano or fissure.
Lavadero (Mexican).—A washer. A tank with a stirring arrangement to loosen up the argentiferous mud from the patio, and dilute the same with water, so that the silver amalgam may have a chance to precipitate. An agitator.
Lazadores (Mexican).—Men formerly employed in recruiting Indians for work in the mines by the gentle persuasion of a lasso.
Lazy Back (Staffordshire).—A coal stack, or pile of coal.
Leaching.—To dissolve out by some liquid.
Lead (pronounced *leed*).—(1) Ledge (America); reef (Australia); lode or vein (England). A more or less vertical deposit of ore formed after the rock in which it occurs. (2) A bed of alluvial pay dirt or an auriferous gutter. (3) The distance to which earth is hauled or wheeled.
Leader.—A seam of coal too small to be worked profitably, but often being a guide to larger seams lying in known proximity to it.
Leat.—A small water ditch.
Leavings (Cornish).—Halvans.
Ledge.—See *Lead.*
Leg.—A wooden prop supporting one end of a collar.
Leg Piece.—An upright log placed against the side of a drive to support the cap piece.
Leñador (Mexican).—One that cuts, carries, or furnishes wood for combustible.
Level.—A road or gangway running parallel or nearly so with the strike of the seam.
Ley (Mexican).—Law. As applied in mining matters, it means the proportion of precious or other metals contained in any mineral substance or metallic alloy.
Lid.—A cap piece used in timbering.

Lift.—(1) The vertical height traveled by a cage in a shaft. (2) The *lift of a pump* is theoretical height from the level of the water in the sump to the point of discharge. (3) The distance between the first level and the surface, or between two levels. (4) The levels of a shaft or slope.
Lifting Guards.—Fencing placed around the mouth of a shaft, which is lifted out of the way by the ascending cage.
Lignite.—A coal of a woody character containing about 66% carbon and having a brown streak.
Limadura (Mexican).—Filings. The mercurial globules seen when a piece of argentiferous mud from a patio is washed in a spoon or saucer for an assay.
Lime Cartridge.—A charge or measured quantity of compressed dry caustic lime made up into a cartridge and used instead of gunpowder for breaking down coal. Water is applied to the cartridge, and the expansion breaks down the coal without producing a flame.
Lime Coal.—Small coal suitable for lime burning.
Lines.—Plumb-lines, not less than two in number, hung from hooks driven in wooden plugs. A line drawn through the centers of the two strings or wires, as the case may be, represents the bearing or course to be driven on.
Lining.—The planks arranged against frame-sets.
Linnets (Derbyshire).—Oxidized lead ores.
Linternilla (Mexican).—The drum of a *Horse Whim.*
Lip Screen.—A small screen or screen bars, placed at the draw hole of a coal pocket to take out the fine coal.
Lis (Mexican).—The flouring of mercury.
Little Giant.—The name given to a special sort of hydraulic nozzle used for sluicing purposes.
Live Quartz.—A variety of quartz usually associated with mineral.
Lixiviating.—See *Leaching.*
Llaves (Mexican).—Horizontal cross-beams in a shaft, or the upright pieces that sustain the roof beams in a drift or tunnel.
Loaded Track.—Track used for loaded cars.
Loader.—One that fills the mine cars at the working places.
Loam.—Any natural mixture of sand and clay that is neither distinctly sandy nor clayey.
Location.—The first approximate staking out or survey of a mining claim, in distinction from a *Patent Survey*, or a *Patented Claim.*
Location Survey.—See *Location.*
Lode (Cornish).—Strictly a fissure in the country rock filled with mineral; usually applied to metalliferous lodes. In general miners' usage, a lode, vein, or ledge is a tabular deposit of valuable minerals between definite boundaries. Whether it be a fissure formation or not is not always known, and does not affect the legal title under the United States federal and local statutes and customs relative to lodes. But it must not be a placer, i. e., it must consist of quartz or other rock in place, and bearing valuable mineral.
Lodestone, or *Lode.*—(1) Magnetic iron ore. (2) Stone found in veins or lodes.
Logs.—Portions of trunks of trees cut to lengths and built up so as to raise the mouth or collar of a shaft from the surface, in order to give the requisite space for the dumping of mullock and ore.
Long-Pillar Work.—A system of working coal seams in three separate opertions: (1) large pillars are left; (2) a number of parallel headings are driven through the block; and (3) the ribs or narrow pillars are worked away in both directions.
Long Tom.—A wooden sluice about 24 ft. long, 2 ft. wide, and 1 ft. high, for washing auriferous gravel.
Long Ton.—2,240 lb.
Longwall.—A system of working a seam of coal in which the whole seam is taken out and no pillars left, excepting the shaft pillars, and sometimes the main-road pillars.
Loob (Cornish).—Sludge from tin dressing.
Loose End.—(1) A portion of a seam worked on two sides. (2) A portion that projects in the shape of a wedge between previous workings.
Low Grade.—Not rich in mineral.
Lumber.—Timber cut to the various sizes and shapes for carpenters' purposes.
Lumbreras (Mexican).—Ventilating shafts in a mine or other underground work.

Lump Coal.—(1) All coal (anthracite only) larger than broken coal, or, when steamboat coal is made, lumps larger than this size. (2) In soft coal, all coal passing over the nut-coal screen.
Lute.—An adhesive clay used either to protect any iron vessel from too strong a heat or for securing air- and gas-tight joints.
Lye (English).—A siding or turnout.

Machote (Mexican).—A stake or permanent bench mark fixed in an underground working, from which the length and progress thereof is measured.
Macizo (Spanish).—Unworked lode.
Magistral (Spanish).—Roasted copper pyrites, copper sulphate, etc., used to reduce silver ores.
Magnetic Needle.—Needle used in surveying.
Magnetic North.—The direction indicated by the north end of the magnetic needle.
Magnetic Meridian.—The line or great circle in which the magnetic needle sets at any given place.
Main Road.—The principal haulage road of a mine from which the several crossroads lead to the working face.
Main Rod (English).—See *Pump Rod.*
Main Rope.—In tail-rope haulage, the rope that draws the loaded cars out.
Makings (North of England).—Small coal produced in kirving. *Fines.*
Malacate (Mexican).—A *Horse Whim;* now extended to any hoisting machine used in mines.
Mamposteria (Mexican).—Mason work.
Manager.—An official who has the control and supervision of a mine, both under and above ground.
Man Engine.—An apparatus consisting of one or two reciprocating rods, to which suitable stages are attached, used for lowering and raising men in shafts.
Manga (Spanish).—Canvas bag for straining amalgam.
Manhole.—(1) A refuge hole constructed in the side of a gangway, tunnel, or slope. (2) A hole in cylindrical boilers through which a man can get into the boiler to examine and repair it.
Mano (Mexican).—A grinding stone of an arrastre, etc.
Mantas (Mexican).—Jute or henequen, etc., sacks in which ore or waste is carried.
Manteo (Mexican).—The act of hoisting ore or waste from a mine.
Manto (Mexican).—A blanket vein.
Manway.—A small passage used as a traveling way for the miner, and also often used as an airway or chute, or both.
Maquilla (Spanish).—A custom mill.
Maquilar (Mexican).—To work ore for its owner on shares or for a money payment.
Marco (Mexican).—A weight of 8 oz.
Marl.—Clay containing calcareous matter.
Marlinespike.—A sharp pointed and gradually tapered round iron, used in splicing ropes.
Marmajas (Spanish).—Concentrated sulphides.
Marrow.—A partner.
Marsaut Lamp.—A type of safety lamp whose chief characteristic is the multiple-gauze chimneys.
Marsh Gas.—CH_4, often used synonymously with *Firedamp* (see page 348).
Match.—(1) A charge of gunpowder put into a paper several inches long, and used for igniting explosives. (2) The touch end of a squib.
Matte.—A compound of iron and other metals, chiefly copper, with sulphur, formed during smelting.
Mattock.—A kind of pick with broad ends for digging.
Maul.—A driver's hammer.
Maundril.—A pick with two shanks and points, used for getting coal, etc.
Mazo (Mexican).—A stamp.
Mear (Derbyshire).—32 yd. along the vein.
Measures.—Strata.
Mecha (Mexican).—A wick for a lamp or candle; a torch.
Merced (Mexican).—A gift, grant, or concession.
Meridian.—A north and south line, either true or approximate.

Metal.—(1) In coal mining, indurated clay or slate. (2) An element that forms a base by combining with oxygen that is solid at ordinary temperature (with exception of quicksilver), opaque (except in the thinnest possible films), has a metallic luster, and is a good conductor of heat and electricity, and, as a rule, of a higher specific gravity than the non-metals. (3) (Mexican) All kinds of metalliferous minerals are called "metal" in Mexico. *Metal de Ayuda.*—Fluxing ore of any kind. *Metal de Cebo.*—Very rich ore, usually treated in small reverberatory furnaces. *Metal Ordinario.*—Common ore. *Metal Pepena.*—The best class of selected ore.
Metlapil (Mexican).—See *Mano.*
Mill.—Works for crushing and amalgamating gold and silver ores.
Mill Cinder.—The slag from the puddling furnace of a rolling mill.
Mill Hole.—An auxiliary shaft connecting a stope or other excavation with the level below.
Mill Run.—The test of a given quantity of ore by actual treatment in a mill.
Mine.—Any excavation made for the extraction of minerals.
Miner.—One who mines.
Mineral.—Any constituent of the earth's crust that has a definite composition.
Mineral Oil.—Petroleum obtained from the earth, and its distillates.
Minero (Mexican).—A mine owner; a mining captain; an underground boss.
Mine Road.—Any mine track used for general haulage.
Mine Run.—The entire unscreened output of a mine.
Minero Mayor (Mexican).—The head mining captain. A mining workman is called *Operario.*
Miners' Dial.—An instrument used in surveying underground workings.
Miners' Inch.—A measure of water varying in different districts, being the quantity of water that passes through a slit 1 in. high, of a certain width under a given head (see page 136).
Miner's Right.—An annual permit from the Government to occupy and work mineral land.
Mining.—In its broad sense, it embraces all that is concerned with the extraction of minerals and their complete utilization.
Mining Engineer.—A man having knowledge and experience in the many departments of mining.
Mining Retreating.—A process of mining by which the vein is untouched until after all the gangways, etc. are driven, when the mineral extraction begins at the boundary and progresses toward the shaft.
Mistress (North of England).—A miner's lamp.
Mock Lead (Cornish).—Zinc blende.
Mogrollo (Mexican).—Same as *Metal de Cebo.*
Moil.—A short length of steel rod tapered to a point, used for cutting hitches, etc.
Molonque (Mexican).—A rich specimen of which one-half or more is native silver.
Monitor.—See *Gunboat.*
Monkey.—The hammer or ram of a pile driver.
Monkey Drift.—A small drift driven in for prospecting purposes, or a crosscut driven to an airway above the gangway.
Monkey Gangway.—A small gangway parallel with the main gangway.
Monkey Rolls.—The smaller rolls in an anthracite breaker.
Monkey Shaft.—A shaft rising from a lower to a higher level.
Monoclinal.—Applied to an area in which the rocks all dip in the same direction.
Mop.—Some material surrounding a drill in the form of a disk, to prevent water from splashing up.
Mortar.—The vessel in which ore is placed to be pulverized by a pestle.
Mortise.—A hole cut in one piece of timber, etc. to receive the tenon that projects from another piece.
Mote (*Moat*).—A straw filled with gunpowder, for igniting a shot.
Mother Gate.—The main road of a district in longwall working.
Mother Lode (*Main Lode*).—The principal vein of any district.
Motive Column.—The length of a column of air whose weight is equal to the difference in weight of like columns of air in downcast and upcast shafts. The ventilating pressure in furnace ventilation is measured by the difference of the weights of the air columns in the two shafts.
Mouth.—The top of a shaft or slope, or the entrance to a drift or tunnel.

Moyle.—An iron with a sharp steel point, for driving into clefts when levering off rock.
Muckle.—Soft clay overlying or underlying coal.
Mucks (Staffordshire).—Bad earthy coal.
Muescas (Mexican).—Notches in a stick; mortises; notches cut in a round or square beam, for the purpose of using it as a ladder.
Mueseler Lamp.—A type of safety lamp invented and used in the collieries of Belgium. Its chief characteristic is the inner sheet-iron chimney for increasing the draft of the lamp.
Muffle.—A thin clay oven heated from the outside.
Muller.—The upper grinding iron or rubbing shoe of amalgamating pans, etc.
Mullock.—Country rock and worthless minerals taken from a mine.
Mundic.—Iron pyrites.

Naked Light.—A candle or any form of lamp that is not a safety lamp.
Narrow Work.—(1) All work for which a price per yard of length driven is paid, and which, therefore, must be measured. (2) Headings, chutes, crosscuts, gangways, etc.
Natas (Mexican).—Same as *Escoria* or *Grasa*.
Native Metal.—A metal found naturally in that state.
Natural Ventilation.—Ventilation of a mine without either furnace or other artificial means; the heat imparted to the air by the strata, men, animals, and lights in the mine, causing it to flow in one direction, or to ascend.
Neck.—A cylindrical body of rock differing from the country around it.
Needle.—(1) A sharp-pointed metal rod with which a small hole is made through the stemming to the cartridge in blasting operations. (2) A hitch cut in the side rock to receive the end of a timber.
Negrillo (Mexican).—Black sulphide of silver.
Nick.—To cut or shear coal after holing.
Nicking.—(1) A vertical cutting or shearing up one side of a face of coal. (2) The chipping of the coal along the rib of an entry or room which is usually the first indications of a squeeze.
Night Shift.—The set of men that work during the night.
Nip.—When the roof and floor of a coal seam come close together, pinching the coal between them.
Nip Out.—The disappearance of a coal seam by the thickening of the adjoining strata, which takes its place.
Nitro.—A corrupted abbreviation for nitroglycerine or dynamite.
Nittings.—Refuse of good ore.
Nodular.—Blistered or kidney-shaped ore.
Nodules.—Concretions that are frequently found to enclose organic remains.
Nogs.—Logs of wood piled one on another to support the roof. See *Chock.*
Nook.—The corner of a working place made by the face with one side.
Noria (Spanish).—An endless chain of buckets.
Nozzle.—The front nose piece of bellows of a blast pipe for a furnace, or of a water pipe.
Nugget.—A natural lump of gold or other metal, applied to any size above 2 to 3 dwt.
Nut Coal.—A contraction of the term chestnut coal.
Nuts.—Small lumps of coal that will pass through a screen or bars, the spaces between which vary in width from ½ to 2½ in.

Ocote (Mexican).—Pitch pine.
Odd Work.—Work other than that done by contract, such as repairing roads, constructing stoppings, dams, etc.
Offtake.—The raised portion of an upcast shaft above the surface, for carrying off smoke and steam, etc., produced by the furnaces and engines underground.
Oil Shale.—Shale containing such a proportion of hydrocarbons as to be capable of yielding mineral oil on slow distillation.
Oil Smellers.—Men that profess to be able to indicate where petroleum oil is to be found.
Old Man.—Old workings in a mine.
Oolitic.—A structure peculiar to certain rocks, resembling the roe of a fish.
Open Cast.—Workings having no roof.

Open Cutting.—(1) An excavation made on the surface for the purpose of getting a face wherein a tunnel can be driven. (2) Any surface excavation.
Openings, An Opening.—Any excavation on a coal or ore bed, or to reach the same; a mine.
Openwork.—An open cut.
Operario (Mexican).—A working miner.
Operator.—The individual or company actually working a colliery.
Ore.—A mineral of sufficient value (as to quality and quantity), to be mined with profit.
Ores.—Minerals or mineral masses from which metals or metallic combinations can be extracted on a large scale in an economic manner.
Ore Shoot.—A large and usually rich aggregation of mineral in a vein. Distinguished from pay streak in that it is a more or less vertical zone or chimney of rich vein matter extending from wall to wall, and having a definite width laterally.
Oro (Spanish).—Gold.
Oroche (Spanish).—(1) Retorted bullion. (2) (Mexican) Bullion containing gold and silver.
Outburst.—A blower. A sudden emission of large quantities of occluded gas.
Outbye.—In the direction of the shaft or slope bottom, or toward the outside.
Outcrop.—The portion of a vein or bed, or any stratum appearing at the surface, or occurring immediately below the soil or diluvial drift.
Outcropping.—See *Cropping Out.*
Outlet.—A passage furnishing an outlet for air, for the miners, for water, or for the mineral mined.
Output.—The product of a mine sent to market, or the total product of a mine.
Outset.—The walling of shafts built up above the original level of the ground.
Outstroke Rent.—The rent that the owner of a royalty receives on coal brought into his royalty from adjacent properties.
Outtake.—The passage by which the ventilating current is taken out of the mine; the upcast.
Overburden.—The covering of rock, earth, etc. overlying a mineral deposit that must be removed before effective work can be performed.
Overcast.—A passage through which the ventilating current is conveyed over a gangway or airway.
Overhand Stoping.—The ordinary method of stoping upwards.
Overlap Fault.—A fault in which the shifted strata double back over themselves.
Overman.—One who has charge of the workings while the men are in the mine. He takes his orders from the *Underviewer.*
Overwind.—To hoist the cage into or over the top of the head-frame.
Oyamel (Mexican).—White pine.

Pack.—A rough wall or block of coal or stone built up to support the roof.
Packing.—The material placed in stuffingboxes, etc. to prevent leaks.
Pack Wall.—A wall of stone or rubbish built on either side of a mine road, to carry the roof and keep the sides up.
Pacos (Spanish).—Ferruginous silver ores.
Paddock.—(1) An excavation made for procuring wash dirt in shallow ground. (2) A place built near the mouth of a shaft where ore is stored.
Paint Gold.—The very finest films of gold coating other minerals.
Paleozoic.—The oldest series of rocks in which fossils of animals occur.
Palero (Mexican).—A mine carpenter.
Palm.—A piece of stout leather fitting the palm of the hand, and secured by a loop to the thumb; this has a flat indented plate for forcing the needle.
Palm Needle.—A straight triangular-sectioned needle, used for sewing canvas.
Palo (Mexican).—A stick; a piece of timber.
Pan.—A thin sheet-iron dish, 16 in. across the top, and 10 in. at the bottom, used for panning gold.
Panel.—(1) A large rectangular block or pillar of coal measuring, say, 130 by 100 yd. (2) A group of breasts or rooms separated from the other workings by large pillars.
Panel Working.—A system of working coal seams in which the colliery is divided up into large squares or panels, isolated or surrounded by solid ribs of coal, in each of which a separate set of breasts and pillars is worked, and the ventilation is kept distinct, that is, every panel has its own circulation, the air of one not passing into the adjoining one, but being carried direct to the main return airway.

Panino (Mexican).—The peculiar appearance, form, or manner in which the metalliferous minerals present themselves in any given district or mine.
Panning, or *Panning Off.*—Separating gold or tin from its accompanying minerals by washing off the latter in a pan.
Parcionero (Mexican).—A partner in a mining contract.
Parrot Coal.—A kind of coal that splits or cracks with a chattering noise when on the fire.
Partido (Mexican).—The division of ores between partners. Working a mine by partido is when the miners agree with the owners to take a certain part of the ores in place of wages. Usually, the mine owner provides candles, powder, and steel, and keeps the drills sharpened, and receives, in payment of royalty and supplies, two-thirds or more of the ore taken out. This contract is renewed weekly or monthly, etc., and the proportion of ore retained by the miners is more or less, according to the richness of the stopes where they work. This is a cheap way of getting ore as far as labor is concerned. But the miners must be constantly watched; otherwise they will leave the mine in bad state. The proportion of ore assigned to the miners is generally bought from them by the mine owner himself, for various reasons.
Parting.—(1) Any thin interstratified bed of earthy material. (2) A side track or turnout in a haulage road.
Pasilla (Spanish).—Dry silver amalgam.
Pass.—(1) A convenient hole for throwing down ore to a lower level. (2) A passage left in old workings for men to travel in from one level to another.
Pass-By.—A siding in which cars pass one another underground. A turnout.
Pass-Into.—When one mineral gradually passes into another without any sudden change.
Patent Fuel.—Small coal mixed with 8 to 10% of pitch or tar, and compressed by machinery into bricks.
Patented Claim.—A claim to which a patent right has been secured from the government, by compliance with the laws relating to such claims.
Patent Survey.—An accurate survey of a claim by a deputized surveyor as required by law in order to secure a patent right to the claim.
Pavement.—The floor.
Patio (Mexican).—Any paved enclosure more or less surrounded by buildings. An ore-sorting yard. A floor or yard where argentiferous mud is treated by amalgamation.
Pay.—Profitable ore.
Pay Dirt.—That portion of an alluvial deposit that contains gold in payable quantities.
Pay Out.—To slacken or let out rope.
Pay Rock—Mineralized rock.
Pay Streak.—Mineralized part of rock.
Peach Stone (Cornish).—Chlorite schist.
Pea Coal.—A small size of anthracite coal (see page 434).
Peas.—Small coal about $\frac{1}{8}$ to $\frac{3}{8}$ in. cube.
Peat.—The decomposed partly carbonized organic matter of bogs, swamps, etc.
Pebble Jack.—Zinc blende in small crystals or pebble-like forms is not attached to rock, but is found in clay openings in the rock.
Pee (Derbyshire).—A fragment of lead ore.
Pella, or *Plata Pella* (Mexican).—Silver amalgam.
Penstock.—See *Forebay.*
Pent House.—A wooden covering for the protection of sinkers working in a pit bottom.
Pentice.—A few pieces of timber laid as a roof over men's heads, to screen them when working in dangerous places, e. g., at the bottom of shafts.
Pepenado (Spanish).—Dressed ore.
Pepenar (Mexican).—To sort ore.
Percussion Table.—A kind of jolting table used in separating very fine ores from slimes.
Pestle.—A hard rod for pounding minerals, etc.
Peter Out.—To "peter out" is to thin out, or gradually decrease in thickness.
Petlanque (Mexican).—Ruby silver.
Petrifaction.—Organic remains converted into stone.
Pick.—(1) A tool for cutting and holing coal. (2) To dress the sides or face of an excavation with a pick.

Picker.—(1) A small tool used to pull up the wick of a miner's lamp. (2) A person who picks the slate from the coal in an anthracite-coal breaker.
Picking Chute.—A chute in an anthracite breaker along which boys are stationed to pick the slate from coal.
Picking Table.—(1) A flat or slightly inclined platform on which anthracite coal is run to be picked free from slate. (2) A sorting table.
Pico (Mexican).—A striking or sledge hammer.
Picture.—A screen to keep off falling water from men at work.
Piedras de Mano (Mexican).—Hand specimens.
Pig.—A piece of lead or iron cast into a long iron mold.
Pigsty Timbering.—Hollow pillows built up of logs of wood laid crosswise for supporting heavy weights.
Pike.—A pick.
Pilar (Mexican).—A pillar of rock or ore left to sustain some portion of the mine.
Pileta (Mexican).—(1) A sump. (2) The basin or pot where melted metal is collected.
Piling.—Long pieces of timber driven into soft ground for the purpose of securing a solid base on which to build any superstructure.
Pillar.—(1) A solid block of coal, etc. varying in area from a few square yards to several acres. (2) Sometimes applied to a single timber support.
Pillar-and-Room.—A system of working coal by which solid blocks of coal are left on either side of the rooms, entries, etc. to support the roof until the rooms are driven up, after which they are drawn out.
Pillar-and-Stall.—See *Breast-and-Pillar.*
Pillar Roads.—Working roads or inclines in pillars having a range of longwall faces on either side.
Pillion (Cornish).—Metal remaining in slag.
Piña (Mexican).—Same as *Pella.*
Pinch.—A contraction in the vein.
Pinch Out.—When a lode runs out to nothing.
Pinta (Mexican).—The color, weight, grain, etc. of ores, whereby it is possible to form some idea of their richness in the various metals.
Pipe.—An elongated body of mineral. Also the name given to the fossil trunks of trees found in coal veins.
Pipe Clay.—A soft white clay.
Piped Air.—Air carried into the working place by pipes or brattices.
Piping.—Undercutting and washing away gravel before the water nozzle.
Pit.—(1) A shaft. (2) The underground portion of a colliery, including all workings. (3) A gravel pit.
Pit Bank.—The raised ground or platform where the coal is sorted and screened at the surface.
Pit Bottom.—The portion of a mine immediately around the bottom of a shaft or slope. See *Shaft Bottom.*
Pitch.—(1) Rise of a seam. (2) Grade of an incline. (3) Inclination. (Cornish) A part of a lode let out to be worked on shares, or by the piece.
Pit Coal.—Generally signifies the bituminous varieties of coal.
Pit Frame.—See *Head-Frame.*
Pit Headman.—The man who has charge at the top of the shaft or slope.
Pitman.—A miner; also, one who looks after the pumps, etc.
Pit Prop.—A piece of timber used as a temporary support for the roof.
Pit Rails.—Mine rails for underground roads.
Pit Room.—The extent of underground workings in use or available for use.
Pit's Eye.—Pit bottom or entrance into a shaft.
Pit Top.—The mouth of a shaft or slope.
Place.—The portion of coal face allotted to a hewer is spoken of as his "working place," or simply "place."
Placer.—A surface accumulation of mineral in the wash of streams.
Placer Mining.—Surface mining for gold where there is but little depth of alluvial.
Plan.—(1) The system on which a colliery is worked as *Longwall, Pillar-and-Breast,* etc. (2) A map or plan of the colliery showing outside improvements and underground workings. (3) (Mexican) The very lowest working in a mine. *Trabajar de Plan.*—To work to gain depth.
Plancha (Mexican).—A pig of lead, etc. A plate, thick sheet, or mass of any metal.

Planchera (Mexican).—A mold of sand, earth, or iron, to form pigs of lead.
Plane.—A main road, either level or inclined, along which coal is conveyed by engine power or gravity.
Plane Table.—A simple surveying instrument by means of which one can plot on the field.
Planilla (Mexican).—An inclined plane of mason work, wood, etc., on which tailings are spread out, to be concentrated by jets of water, skilfully applied.
Planillero (Mexican).—A workman who devotes himself to concentrating tailings, etc. on the *Planillas;* always paid by weight, measure, or concentrates produced.
Plank Dam.—A water-tight stopping fixed in a heading constructed of timber placed across the passage, one upon another, sidewise, and tightly wedged.
Plank Tubbing.—Shaft lining of planks driven down vertically behind wooden cribs all around the shaft, all joints being tightly wedged, to keep back the water.
Plant.—The shafts or slope, tunnels, engine houses, railways, machinery, workshops, etc. of a colliery or other mine.
Plat, or *Map.*—A map of the surface and underground workings, or of either, to draw such a map from survey.
Plata (Spanish).—Silver.
Plata Blanca (Mexican).—Native silver.
Plata Cornea Amarillia (Spanish).—Iodyrite.
Plata Cornea Blanca (Spanish).—Cerargyrite.
Plata Cornea Verde (Spanish).—Embolite.
Plata Mixta (Spanish).—Gold and silver alloy.
Plata Negra (Spanish).—Argentite.
Plata Pasta (Spanish).—Spongy silver bars after retorting.
Plata Piha (Spanish).—Silver after retorting.
Plata Verde (Spanish).—Bromyrite.
Plate (North of England).—Scaly shale in limestone beds.
Plates.—Metal rails 4 ft. long.
Plenum.—A mode of ventilating a mine or a heading by forcing fresh air into it.
Plomada (Mexican).—A plumb-line or plumb-bob.
Plomb d'Oeuvre (French).—Dressed galena.
Plomillos (Mexican).—Shots of lead found in slags.
Plomo (Spanish).—Lead, galena.
Plugging.—When drift water forces its way through the puddle clay into the shaft, holes are bored through the slabs near the leakage point, and plugs of clay forced into them until the leakage is stopped.
Plumb.—Vertical.
Plummet.—(1) A heavy weight attached to a string or fine copper wire used for determining the verticality of shaft timbering. (2) A plumb-bob for setting a surveying instrument over a point.
Plunger.—The solid ram of a force pump working in the plunger case.
Plunger Case.—The pump cylinder or barrel in which the plunger works.
Plush Copper.—Chalcotrichite.
Plwm (Welsh).—Lead.
Poblar (Mexican).—To set men at work in a mine.
Pocket.—(1) A thickening out of a seam of coal or other mineral over a small area. (2) A hopper-shaped receptacle from which coal or ore is loaded into cars or boats.
Podar (Cornish).—Copper pyrites.
Pole Tools.—Drilling tools used in drilling in the old fashion with rods, now superseded by the rope-drilling method.
Polroz (Cornish).—Waterwheel pit.
Poling.—Refining metal, when in a molten condition, by stirring it up with a green pole of wood.
Poll Pick.—A pick having the longer end pointed and the shorter end hammer-shaped.
Polvillos (Spanish).—Rich ores or concentrates.
Polvoulla (Spanish).—Black silver.
Poppet Heads.—The pulley frame or hoisting gear over a shaft.
Poppet (*Puppet*).—(1) A pulley frame or the head-gear over a shaft. (2) A valve that lifts bodily from its seat instead of being hinged.

Post.—(1) Any upright timber; applied particularly to the timbers used for propping. See *Prop.* (2) Local term for sandstone. Post stone may be "strong," "framey," "short," or "broken."
Post-and-Stall.—A system of working coal much the same as *Pillar-and-Stall.*
Post Tertiary.—Strata younger than the Tertiary formation.
Pot Bottom.—A large boulder in the roof slate, having the appearance of the rounded bottom of a pot, and which easily becomes detached.
Pot Growan (Cornish).—Decomposed granite.
Pot Hole.—A circular hole in the rock caused by the action of stones whirled around by the water when the strata was covered by water. They are generally filled with sand and drift.
Power Drill.—A rock drill employing steam, air, or electricity as a motor.
Prian (Cornish).—Soft white clay.
Pricker.—(1) A thin brass rod for making a hole in the stemming when blasting, for the insertion of a fuse. (2) A piece of bent wire by which the size of the flame in a safety lamp is regulated without removing the top of the lamp.
Prill.—(1) An extra-rich stone of ore. (2) A bead of metal.
Prong (English).—The forked end of the bucket-pump rods for attachment to the traveling valve and seat.
Prop.—A wooden or cast-iron temporary support for the roof.
Propping.—The timbering of a mine.
Prospect.—The name given to underground workings whose value has not yet been made manifest. A prospect is to a mine what mineral is to ore.
Prospect Hole.—Any shaft or drift hole put down for the purpose of prospecting the ground.
Prospect Tunnel or Entry.—A tunnel or entry driven through barren measures or a fault to ascertain the character of strata beyond.
Prospecting.—Examining a tract of country in search of minerals.
Prospector.—One engaged in searching for minerals.
Protector Lamp.—A safety lamp whose flame cannot be exposed to the outward atmosphere, as the action of opening the lamp extinguishes the light.
Prove.—(1) To ascertain, by boring, driving, etc., the position and character of a coal seam, a fault, etc. (2) To examine a mine in search of fire-damp, etc., known as "proving the pit."
Proving Hole.—(1) A bore hole driven for prospecting purposes. (2) A small heading driven in to find a bed or vein lost by a dislocation of the strata, or to prove the quality of the mineral in advance of the other workings.
Pudding Machine.—A circular machine for washing pay dirt.
Pudding Rock.—Conglomerate.
Puddle.—(1) Earth well rammed into a trench, etc., to prevent leaking. (2) A process for converting cast iron into wrought iron.
Pueble (Mexican).—The actual working of a mine; the aggregation of persons employed therein.
Puertas (Mexican).—Massive barren rocks, or "horses," occurring in a vein.
Pug Mill.—A mill for preparing clay for bricks, pottery, etc.
Pulley.—(1) The wheel over which a winding rope passes at the top of the head-gear. (2) Small wooden cylinders over which a winding rope is carried on the floor or sides of a plane.
Pulleying.—Overwinding or drawing up a cage into the pulley frame.
Pulp.—Crushed ore, wet or dry.
Pump.—Any mechanism for raising water.
Pump Bob.—See *Bob.*
Pump Ring.—A flat iron ring that, when lapped with tarred baize or engine shag, secures the joints of water columns.
Pump Rods.—Heavy timbers by which the motion of the engine is transmitted to the pump. In Cornish and bull pumps, the weight of the rods makes the effective (pumping) stroke, the engine merely lifting the rods on the up stroke.
Pump Slope.—A slope used for pumping machinery.
Pump Station.—An enlargement made in the shaft, slope, or gangway, to receive the pump.
Pump Tree.—Cast-iron pipes, generally 9 ft. long, of which the column or set is formed.
Punch-and-Thirl.—A kind of pillar-and-stall system of working.

Punch Prop.—A short timber prop set on the top of a crown tree, or used in holding, as a sprag.
Putty Stones.—Soft pieces of decomposed rock found in placer deposits.
Pyran (Cornish).—See *Prian.*
Pyrites.—Sulphide of iron.
Pyrometer.—An instrument for measuring high degrees of heat.

Quajado (Spanish).—Dull lead ore.
Quarry.—(1) An open surface excavation for working valuable rocks or minerals. (2) An underground excavation for obtaining stone for stowage or pack walls.
Quartz Bucket.—A bucket for hoisting quartz.
Quaternary.—Post-tertiary period.
Quemadero (Mexican).—A burning place; a retorting furnace for silver or gold amalgam.
Quemados (Mexican).—Burnt stuff. Any dark cinder-like mineral encountered in a vein or mineral deposit, generally manganiferous.
Queme (Mexican).—A roast of ore; the process of roasting ore.
Quick (Adjective).—Soft, running ground; an ore or pay streak is said to be quickening when the associated minerals indicate richer mineral ahead. *Quick* (Noun).—(1) Productive. (2) Mercury.
Quicksand.—Soft watery strata easily moved, or readily yielding to pressure.
Quicksilver.—Mercury.
Quillato (Spanish).—Carat.
Quitapepena (Mexican).—A watchman that searches the miners as they come out at the mouth of a mine.

Rabban (Cornish).—Yellow dry gossan.
Rabbling.—Stirring up a charge of ore in a reverberatory furnace with specially designed iron rods.
Race.—A channel for conducting water to or from the place where it performs work. The former is termed the headrace, and the latter the tailrace.
Rack (Cornish).—A stationary buddle.
Raff.—The coarse ore after crushing by Cornish rolls.
Raffain (Cornish).—Poor ore.
Raff Wheel.—A revolving wheel with side buckets for elevating the raff.
Rafter Timbering.—That in which the timbers appear like roof rafters.
Rag Burning (Cornish).—The first roasting of tin-witts.
Ragging (Cornish). Rough cobbing.
Rag Wheel.—Sprocket wheel. A wheel with teeth or pins that catch into the links of chains.
Rails.—The iron or steel portion of the tramway or railroad.
Rake (Cornish).—(1) A vein. (2) (Derbyshire) Fissure vein crossing strata.
Ram.—(1) The plunger of a pump. (2) A device for raising water.
Ramal (Mexican).—A branch vein.
Ramalear (Mexican).—To branch off into various divisions.
Ramble.—Stone of little coherence above a seam that falls readily on the removal of the coal. See *Following Stone.*
Rance.—A pillar of coal.
Rapper.—A lever with a hammer attached at one end, which signals by striking a plate of metal, when the signaling wire to which it is attached is pulled.
Rash.—A term used to designate the bottom of a mine when soft and slaty.
Rastrillo (Mexican).—A rake; a stirrer for moving ore in a furnace.
Rastron (Mexican).—A Chilian mill.
Raw Ore.—Not roasted or calcined.
Reacher.—A slim prop reaching from one wall to the other.
Reamer.—An enlarging tool.
Reaming.—Enlarging the diameter of a bore hole.
Receiving Pit.—A shallow pit for containing material run into it.
Red-Ash Coal.—Coal that produces a reddish ash, when burnt.
Red Rab (Cornish).—Red slaty rock.
Reduced.—When a metal is freed from its chemical associate it is said to be reduced to the metallic state.
Reduction Works.—Works for reducing metals from their ores.
Reef.—(1) A vein of quartz. (2) Bed rock of alluvial claims.
Reef Drive.—In alluvial mines, drives made in the country rock or reef.

Refining.—The freeing of metals from impurities.
Refractory.—Rebellious ore, not easily treated by ordinary processes.
Refuge Hole.—A place formed in the side of an underground plane in which a man can take refuge during the passing of a train, or when shots are fired.
Regulator.—A door in a mine, the opening or shutting of which regulates the supply of ventilation to a district of the mine.
Regulus.—See *Matte.*
Relampago, or *Relampaguear* (Mexican).—The brightening of the silver button during cupellation.
Reliz (Spanish).—Wall of lode.
Rendir (Mexican).—Is when all the silver has been amalgamated in a heap of argentiferous mud on a patio.
Rendrock.—A variety of dynamite.
Repairman.—A workman whose duty it is to repair tracks, doors, brattices, or to reset timbers, etc., under the direction of the foreman.
Repaso-Repasar (Mexican).—The art of mixing up the mud heaps in the patio process of amalgamation by treading them over with horses or mules.
Repos Adero (Mexican).—The bottom of a crucible or pot in an upright smelting furnace.
Rescatadores (Mexican).—Ore buyers.
Reserve.—Mineral already opened up by shafts, winzes, levels, etc., which may be broken at short notice for any emergency.
Reservoir.—An artificially built, dammed, or excavated place for holding a reserve of water.
Respaldos (Mexican).—The walls enclosing a vein. *Respaldo Alto.*—The hanging wall. *Respaldo Bajo.*—The foot-wall.
Rests, Keeps, Wings.—Supports on which a cage rests when the loaded car is being taken off and the empty one put on.
Resue.—See *Stripping.*
Retort.—(1) A vessel with a long neck, used for distilling the quicksilver from amalgam. (2) The vessel used in distilling zinc.
Return.—The air-course along which the vitiated air of a mine is returned or conducted back to the upcast shaft.
Return Air.—The air that has been passed through the workings.
Reverberatory.—A class of furnaces in which the flame from the fire-grate is made to beat down on the charge in the body of the furnace.
Reversed Fault.—See *Overlap Fault.*
Rib.—The side of a pillar.
Rib-and-Pillar.—A system of working similar to *Pillar-and-Stall.*
Ribbon.—A line of bedding or a thin bed appearing on the cleavage surface and sometimes of a different color.
Rick.—Open heap in which coal is coked.
Ridding.—Clearing away fallen stone and débris.
Riddle.—An oblong frame holding iron bars parallel to each other, used for sifting material that is thrown against it.
Ride, Riding.—To be conveyed on a cage or mine car.
Rider.—(1) A guide frame for steadying a sinking bucket. (2) Boys that ride on trips on mechanical haulage roads. (3) A thin seam of coal overlying a thicker one.
Riffle, or *Ripple.*—Crosspieces placed on the bottom of a sluice to save gold; or grooves cut across inclined tables.
Right Shore.—The right shore of a river is on the right hand when descending the river.
Rill.—The coarse ore at the periphery of a pile.
Rim Rock.—Bed rock forming a boundary to gravel deposit.
Ring.—(1) A complete circle of tubbing plates placed round a circular shaft. (2) Troughs placed in shafts to catch the falling water, and so arranged as to convey it to a certain point.
Ripping.—Removing stone from its natural position above the seam.
Riscos (Mexican).—Sharp and precipitous rocks; amorphous quartz found in veins or outcrops.
Rise.—The inclination of the strata, when looking up the pitch.
Rise Workings.—Underground workings carried on to the rise or high side of the shaft.
River Mining.—Working beds of existing rivers by deflecting their course or by dredging.

Road.—(1) Any underground passageway or gallery. (2) The iron rails, etc. of underground roads.
Roasting.—Heating ores at a temperature sufficient to cause a chemical change, but not enough to smelt them.
Rob.—To cut away or reduce the size of pillars of coal.
Robbing.—The taking of mineral from pillars.
Robbing an Entry.—See *Drawing an Entry.*
Rock.—A mixture of different minerals in varying proportions.
Rock Breaker.—A machine for reducing ore in size by crunching it between powerful jaws.
Rock Chute.—See *Slate Chute.*
Rock Drill.—A rock-boring machine worked by hand, compressed air, steam, or electrical power.
Rocker.—See *Cradle.*
Rock Fault.—A replacement of a coal seam over greater or less area, by some other rock, usually sandstone.
Rodding.—The operation of fixing or repairing wooden eye guides in shafts.
Roll.—An inequality in the roof or floor of a mine.
Roller.—A small steel, iron, or wooden wheel or cylinder upon which the hauling rope is carried just above the floor.
Rolleyway.—A main haulage road.
Rolling Ground.—When the surface is much varied by many small hills and valleys.
Rolls.—Cast-iron cylinders, either plain or fitted with steel teeth, used to break coal and other materials into various sizes.
Roof.—The top of any subterranean passage.
Room.—Synonymous with *Breast.*
Room-and-Rance.—A system of working coal similar to *Pillar-and-Stall.*
Rope Roll.—The drum of a winding engine.
Rosiclara (Spanish).—Ruby silver ore.
Roughs (Cornish).—Second quality tin sands.
Round Coal.—Coal in large lumps, either hand-picked, or, after passing over screens, to take out the small.
Royalty.—The price paid per ton to the owner of mineral land by the lessee.
Rubbing Surface.—The total area of a given length of airway; that is, the area of top, bottom, and sides added together, or the perimeter multiplied by the length.
Rubble.—Coarse pieces of rock.
Rumbo (Mexican).—The course or direction of a vein.
Run.—(1) The sliding and crushing of pillars of coal. (2) The length of a lease or tract on the strike of the seam.
Run Coal.—Soft bituminous coal.
Rung, Rundle, or *Round.*—A step or cross-bar of a ladder.
Runner.—A man or boy whose duty it is to run mine cars by gravity from working places to the gangway.
Running Lift.—A sinking set of pumps constructed to lengthen or shorten at will, by means of a sliding or telescoping wind bore.
Rush.—An old-fashioned way of exploding blasts by filling a hollow stalk with slow powder and then igniting it.
Rush Gold.—Gold coated with oxide of iron or manganese.
Rush Together.—See *Caved In.*
Rusty.—Stained by iron oxide.

Saca (Mexican).—A bagful of ore. A mine is said to be *de buena saca* when it has large quantities of ore easy to get out.
Saddle.—An anticlinal, a hogback.
Saddleback.—A depression in the strata. See *Roll.*
Saddle Reef.—A reef having the form of an inverted **V**.
Safety Cage.—A cage fitted with an apparatus for arresting its motion in the shaft in case the rope breaks.
Safety Car.—See *Barney.*
Safety Catches.—Appliances fitted to cages, to make them safety cages.
Safety Door.—A strongly constructed door, hinged to the roof, and always kept open and hung near to the main door, for immediate use when main door is damaged by an explosion or otherwise.
Safety Fuse.—A cord with slow-burning powder in the center for exploding charged blast holes.

Safety Lamp.—A miner's lamp in which the flame is protected in such a manner that an explosive mixture of air and firedamp can be detected by the mixture burning inside the gauze.
Sag.—A depression, e. g., in ropes, ranges of mountains, etc.
Sagre, or *Seggar.*—A local term for fireclay, often forming the floor (or thill) of coal seams.
Salting.—(1) Changing the value of the ore in a mine or of ore samples before they have been assayed, so that the assay will show much higher values than it should. (2) Sprinkling salt on the floors of underground passages in very dry mines, in order to lay the dust.
Sampler.—(1) An instrument or apparatus for taking samples. (2) One whose duty it is to select the samples for an assay, or to prepare the mineral to be assayed, by grinding and sampling.
Sampling Works.—Works for sampling and determining the values obtained in ores; where ores are bought and sold.
Samson Post.—An upright supporting the working beam that communicates oscillatory motion to pump or drill rod.
Sand Bag.—A bag filled with sand for preventing a washout by obstructing the flow.
Sand Pump.—A sludger; a cylinder provided with a stem (or other) valve, lowered into a drill hole to remove the pulverized rock.
Scaffolding.—Incrustations on the inside of a blast furnace.
Scale.—(1) A small portion of the ventilating current in a mine passing through a certain size of aperture. (2) The rate of wages to be paid, which varies under certain contingencies.
Scale Door.—See *Regulator.*
Scallop.—To hew coal without kirving or nicking or shot firing.
Schist.—Crystalline or metamorphic rocks having a slaty structure.
Schute.—See *Chute.*
Scissors Fault.—A fault of dislocation, in which two beds are thrown so as to cross each other.
Scoop.—A large-sized shovel with a scoop-shaped blade.
Scoria.—Ashes.
Scorifier.—A small dish used in assaying.
Scovan (Cornish).—A tin lode showing no gossan at surface.
Scove (Cornish).—Purest tin ore.
Scramming.—Cleaning up small bodies or patches of ore left in the ordinary process of mining.
Scraper.—(1) A tool for cleaning the dust out of the bore hole. (2) A mechanical contrivance used at colleries to scrape the culm or slack along a trough to the place of deposit.
Scrapper.—A local name given to parties that pick up the ore left on dumps.
Screen.—(1) A mechanical apparatus for sizing materials. (2) A cloth brattice or curtain hung across a road in a mine, to direct the ventilation.
Scrin (Derbyshire).—A small vein.
Scrowl (Cornish).—Loose ore where a vein is crossed.
Sculping.—Fracturing the slate along the grain, i. e., across the cleavage.
Scupper Nails.—Nails with broad heads, for nailing down canvas, etc.
Sea Coal.—That which is transported by sea.
Sealing.—Shutting off all air from a mine or a part of a mine by stoppings.
Seam.—(1) Synonymous with *Bed*, *Vein*, etc. (2) (Cornish) A horse load of ore.
Seam-Out.—A term applied to a shot or blast that has simply blown out a softer stratum of the deposit in which it was placed, without dislodging the other strata or layers of the seam.
Second Outlet (*Second Opening*).—A passageway out of a mine, for use in case of accident to the main outlet.
Seconds.—The second-class ore of a mine that requires dressing.
Second Working.—The operation of getting or working out the pillars formed by the first working.
Section.—(1) A vertical or horizontal exposure of strata. (2) A drawing or sketch representing the rock strata as cut by a vertical or a horizontal plane.
Sedimentary Rocks.—Rocks formed from deposits of sediment by wind or water.
Seedbag.—A water-tight packing of flaxseed around the tube of a drill hole, to prevent the influx into the hole of water from above.
Segregations.—Detached portions of veins in place.

Self-Acting Plane.—An inclined plane upon which the weight or force of gravity acting on the full cars is sufficient to overcome the resistance of the empties; in other words, the full car, running down, pulls the other car up.
Self-Detaching Hook.—A self-acting hook for setting free a hoisting rope in case of overwinding.
Self-Feeders.—Automatic appliances for feeding ore-dressing machines.
Selvage.—The clay seam on the walls of veins; gouge.
Separation Doors.—The main doors at or near the shaft or slope bottom, which separate the intake from the return airways.
Separation Valve.—A massive cast-iron plate suspended from the roof of a return airway through which all the return air of a separate district flows, allowing the air to always flow past or underneath it; but in the event of an explosion of gas, the force of the blast closes it against its frame or seating, and prevents a communication with other districts. The blast being over, the weight of the valve allows it to return to its normal position.
Set.—To fix in place a prop or sprag.
Set Hammer.—The flat-faced hammer held on hot iron by a blacksmith when shaping or smoothing a surface by aid of his striker's sledge.
Set of Timber.—The timbers which compose any framing, whether used in a shaft, slope, level, or gangway. Thus, the four pieces forming a single course in the curbing of a shaft, or the three or four pieces forming the legs and collar, and sometimes the sill of an entry framing are together called a set of timber, or timber set.
Shackle.—A U-shaped link in a chain closed by a pin; when the latter is withdrawn the chain is severed at that point.
Shadd (Cornish).—Rounded fragments of ore overlying a vein.
Shaft.—A vertical or highly inclined pit or hole made through strata, through which the product of the mine is hoisted, and through which the ventilation is passed either into or out of the mine. A shaft sunk from one seam to another is called a "blind shaft."
Shaft Pillar.—Solid material left unworked beneath buildings and around the shaft, to support them against subsidence.
Shaking Table.—An inclined table for concentrating fine grains of ore, which is rapidly shaken by a short motion
Shale.—(1) Strictly speaking, all argillaceous strata that split up or peel off in thin laminæ. (2) A laminated and stratified sedimentary deposit of clay, often impregnated with bituminous matter.
Shank.—The body portion of any tool, up from its cutting edge or bit.
Shearing.—Cutting a vertical groove in a coal face or breast. The cutting of a "fast end" of coal.
Shear Legs.—A high wooden frame placed over an engine or pumping shaft fitted with small pulleys and rope for lifting heavy weights.
Shears, or *Sheers* (English).—Two tall poles, with their feet some distance apart and their tops fastened together, for supporting hoisting tackle.
Shear Zone.—Hogback.
Sheave.—A wheel with a grooved circumference over which a rope is turned either for the transmission of power or for winding or hauling.
Sheel Pump.—See *Sludger*.
Sheets.—Coarse cloth curtains or screens for directing the ventilating current underground.
Shelly.—A name applied to coal that has been so crushed and fractured that it easily breaks up into small pieces. The term is also applied to a laminated roof that sounds hollow and breaks into thin layers of slate or shale.
Shet (Staffordshire).—Fallen roof of coal mine.
Sheth.—An old term denoting a district of about eight or nine adjacent bords. Thus, a "sheth of bords," or a "sheth of pillars."
Shift.—(1) The number of hours worked without change. (2) A gang or force of workmen employed at one time upon any work, as the day shift, or the night shift.
Shoad (Cornish).—See *Shadd.*
Shoading (Cornish).—Prospecting.
Shoe.—(1) A steel or iron guide piece fixed to the ends or sides of cages, to fit or run on the conductors. (2) The upper working face of a stamp or grinding pan. (3) The lower capping of any post or pile, to protect its end while driving. (4) A wooden or sheet-iron frame or muff arranged

at the bottom of a shaft while sinking through quicksand, to prevent the inflow of sand while inserting the shaft lining.

Shoot, Chute, Shute.—(1) A run of rich material in a vein. (2) An inclined or vertical trough or pipe for conveying materials from a higher to a lower level.

Shoot.—To break rock or coal by means of explosives.

Shooting.—Blasting in a mine.

Shore (English).—A studdle or thrusting stay.

Shore Up.—To stay, prop up, or support by braces.

Shot.—(1) A charge or blast. (2) The firing of a blast. (3) Injured by a blast.

Shot-Firer.—See *Shot Lighter.*

Shot Hole.—The bore hole in which an explosive substance is placed for blasting.

Shot Lighter, or *Shot Firer.*—A man specially appointed by the manager of the mine to fire off every shot in a certain district, if, after he has examined the immediate neighborhood of the shot, he finds it free from gas, and otherwise safe.

Shotty Gold.—Granular pieces like shot.

Show.—When the flame of a safety lamp becomes elongated or unsteady, owing to the presence of firedamp in the air, it is said to show.

Showing.—The first appearance of float, indicating the approach to an outcropping vein or seam. Blossom.

Shroud.—A housing or jacket.

Shute.—See *Chute, Shoot*, and *Schute.*

Shutter.—(1) A movable sliding door, fitted within the outer casing of a Guibal or other closed fan, for regulating the size of the opening from the fan, to suit the ventilation and economical working of the machine. (2) A slide covering the opening in a door or brattice, and forming a regulator for the proportionate division of the air-current between two or more districts of a mine.

Sickening.—A coating of impurities on quicksilver that retards amalgamation or the coalescence of the globules of quicksilver.

Siddle.—Inclination.

Side.—(1) The more or less vertical face or wall of coal or goaf forming one side of an underground working place. (2) Rib. (3) A district.

Side Chain.—A chain hooked on to the sides of cars running on an incline or along a gangway, to keep the cars together in case the coupling breaks.

Sidelong Reef.—An overhanging wall of bed rock in alluvial formations running parallel with the course of the gutter; generally only on one side of it.

Siding.—A short piece of track parallel to the main track, to serve as a passing place.

Siding Over.—A short road driven in a pillar in a headwise direction.

Sight.—(1) A bearing or angle taken with a compass or transit when making a survey. (2) Any established point of a survey.

Sights.—Bobs or weighted strings hung from two or more established points in the roof of a room or entry, to give direction to the men driving the entry or room.

Sill.—(1) The floor piece of a timber set, or that on which the track rests; the base of any framing or structure. (2) The floor of a seam.

Silver.—(1) A certain white ductile and valuable metal. (2) Short for quicksilver.

Sing.—The noise made by a feeder of gas issuing from the coal.

Singing Coal.—Coal from which gas is issuing with a hissing sound.

Singing Lamp.—A safety lamp, which, when placed in an atmosphere of explosive gas, gives out a peculiar sound or note, the strength of the note varying in proportion to the percentage of firedamp present.

Single-Entry System.—A system of opening a mine by driving a single entry only, in place of a pair of entries. The air-current returns along the face of the rooms, which must be kept open.

Single-Intake Fan.—A ventilating fan that takes or receives its air upon one side only.

Single-Rope Haulage.—A system of underground haulage in which a single rope is used, the empty trip running in by gravity. This is engine-plane haulage.

Sink.—To excavate a shaft or slope; to bore or put down a bore hole.

Sinker.—A man who works at the bottom of a shaft or face of a slope during the course of sinking.
Sinker Bar.—In rope drilling, a heavy bar attached above the jars, to give force to the up stroke, so as to dislodge the bit in the hole.
Sinking.—The process of excavating a shaft or slope or boring a hole.
Siphon.—A simple, effective, and economical mode of conveying water over a hill whose height is not greater than what the atmospheric pressure will raise the water. Its form is that of an iron pipe, bent like an inverted U; the vertical height between the surface of the water in the upper basin and the top of the hill is called the lift of the siphon; while the vertical height between the surfaces of the water in the upper and lower basins is called the fall of the siphon.
Sizing.—To sort minerals into sizes.
Skew Back.—The beveled stone from which an arch springs, and upon which it rests.
Skids.—Slides upon which heavy bodies are slid from place to place.
Skimpings (Cornish).—The poorest ore skimmed off the jigger.
Skip.—(1) A mine car. (2) A car for hoisting out of a slope. (3) A thin slice taken off from a breast or pillar or rib along its entire length or part of its length.
Skirting.—Road opened up or driven next a fall of stone, or an old fallen place.
Skit (Cornish).—A pump.
Slab.—Split pieces of timber from 2 in. to 3 in. thick, 4 ft. to 6 ft. long, and 7 in. to 14 in. wide, placed behind sets or frames of timber in shafts or levels.
Slack.—(1) Fine coal that will pass through the smallest sized screen. The fine coal and dust resulting from the handling of coal, and the disintegration of soft coal. (2) The process by which soft coal disintegrates when exposed to the air and weather.
Slag.—The liquid refuse from a smelting operation, which floats on top of the metal.
Slant.—(1) An underground roadway driven at an angle between the full rise or dip of the seam and the strike or level. (2) Any inclined road in a seam.
Slant Chutes.—Chutes driven diagonally across a pillar, to connect a breast manway with a manway chute.
Slate.—(1) A hardened clay having a peculiar cleavage. (2) About coal mines, slate is any shale accompanying the coal, also sometimes applied to bony coal.
Slate Picker.—(1) A man or boy that picks the slate or bony coal from anthracite coal. (2) A mechanical contrivance for separating slate and coal.
Slate Chute.—(1) A chute for conveying slate or bony coal to a pocket from which it is loaded into "dumpers." (2) A chute driven through slate.
Sleck (Derbyshire).—Mud in a mine.
Sled.—A drag used to convey coal along the face to the road head where it is loaded, or to the chute.
Sledge.—A heavy double-handed hammer.
Sleeper (English).—The foundation pieces or cross-ties on which rails rest.
Sleeping Table (Cornish).—A buddle.
Sleeve.—A hollow cylinder fitting over two pieces, to hold them together.
Slickensides.—Polished surfaces of vein walls.
Slide.—Loose deposit covering the outcrop of a seam.
Slides.—See *Guides.*
Sliding Scale.—A mode of regulating the wages paid workingmen by taking as a basis for calculation the market price of coal, the wages rising and falling with the state of trade.
Sliding Wind Bore (English).—The bottom pipe or suction piece of a sinking set of pumps having a lining made to slide like a telescope within it, to give length without altering the adjustment of the whole column of pipes.
Slime, Sludge.—(1) The pulp or fine mud from a mill or from a drill hole. (2) Silt containing a very fine ore, which passes off in the water from the jigs.
Slings.—Pieces of ropes or chains to be put around stones, etc. for raising them.
Slip.—(1) A fault. (2) A smooth joint or crack where the strata have moved upon each other.

Slip Cleavage.—Microscopic folding and fracture accompanied by slippage; quarrymen's "false cleavage."
Slit.—A short heading put through to connect two other headings.
Slitter.—See *Pick.*
Slope.—A plane or inclined roadway, usually driven in the seam from the surface. A rock slope is a slope driven across the strata, to connect two seams; or a slope opening driven from the surface, to reach a seam below that does not outcrop at an accessible point.
Sludge.—See *Slime.*
Sludger, Sludge Pump.—A cylinder having an upward opening valve at the bottom, which is lowered into a bore hole, to pump out the sludge or fine rock resulting from drillings.
Sluice.—(1) A long channel in rock or built of timber, with checks to catch gold. (2) Any overflow channel.
Sluice Box.—A trough with ripples or false bottom for catching gold.
Sluice Head, or *Head* (Australia and New Zealand).—A supply of 1 cu. ft. of water per second, regardless of the head, pressure, or size of orifice.
Sluicing.—Ground sluicing is working gravel by excavating with pick and shovel, and washing the débris in trenches with water not under pressure.
Slurry (North of Wales).—Half-smelted ore.
Small.—See *Slack.*
Smeddum.—Lead-ore dust.
Smelting.—Method of extracting a precious metal from its ores.
Smift, Snift.—A bit of touch paper, touch wood, etc. attached by a bit of clay or grease to the outside end of the train of gunpowder when blasting.
Smittem.—Fine gravel-like ore, occurring free in mud openings, or derived from the breaking of the ore in blasting.
Smut (Staffordshire).—Soft, bad coal.
Snore, Snore Piece.—The hole in the lower part of a sinking or Cornish pump, through which water enters.
Soapstone.—A term incorrectly applied by the miner to any soft, unctuous rock.
Socabon (Mexican).—A mining tunnel; an adit. *Socavon á hilo de veta.*—A drift tunnel. *Socavon crucero.*—A crosscut tunnel or adit.
Socket.—(1) The innermost end of a shot hole, not blown away after firing. (2) A wrought-iron contrivance by means of which a wire rope is securely attached to a chain or block.
Sole, Sole Plate.—A piece of timber set underneath a prop.
Sollar.—A wooden platform fixed in a shaft, for the ladders to rest on.
Sondear (Mexican).—To bore for prospecting purposes.
Sondeo (Mexican).—A boring for prospecting purposes.
Soplete (Mexican).—A blowpipe. *Ensaye al Soplete.*—A blowpipe assay.
Sorting.—Separating valuable from worthless material.
Sounding.—(1) Knocking on a roof to see whether it is sound or safe to work under. (2) Rapping on a pillar so that a person on the other side of it may be signaled to, or to enable him to estimate its width.
Sow.—(1) A tool used for sharpening drills. (2) Iron deposits at the bottom of furnaces.
Spall.—To break up rocks with a large hammer, for hand sorting.
Spalls.—The chips and other waste material cut from a block of stone in process of dressing.
Spar.—A name given to certain white quartz-like minerals, e. g., calcspar, feldspar, fluorspar.
Spears.—Pump-rods.
Specimen.—A picked piece of mineral.
Speiss.—A basic arsenide or antimonide of iron, often containing nickel, cobalt, lead, bismuth, copper, etc., having a metallic luster of high specific gravity and a strong tendency toward crystallization.
Spelter.—The commercial name for zinc.
Spent Shot.—A blast hole that has been fired, but has not done its work.
Spew.—The extension of mineral matter on the surface, past the ordinary limits of the lode.
Spiders.—See *Drum Rings.*
Spiegeleisen.—Manganiferous white cast iron.
Spiking Curbs.—A light ring of wood to which planks are spiked when plank tubbing is used.

Spiles (Cornish).—A temporary lagging driven ahead on levels in loose ground. Short pieces of planking sharpened flatways, and used for driving into watery strata as sheath piling, to assist in checking the flow; used much in sinking through quicksands.
Spiling.—A process of timbering through soft ground.
Spiral Drum.—See *Conical Drum.*
Splint, or *Splent.*—A laminated, coarse, inferior, dull-looking, hard coal, producing much white ash, intermediate between cannel and bituminous coal.
Split.—(1) To divide an air-current into two or more separate currents. (2) Any division or branch of the ventilating current. (3) The workings ventilated by that branch. (4) Any member of a coal bed split by thick partings into two or more seams. (5) A bench separated by a considerable interval from the other benches of a coal bed.
Spoil.—Débris from a coal mine.
Spoon.—A slender iron rod with a cup-shaped projection at right angles to the rod, used for scraping drillings out of a bore hole.
Spout.—A short underground passage connecting a main road with an air-course.
Sprag.—(1) A short wooden prop set in a slanting position for keeping up the coal during the operation of holing. (2) A short round piece of hard wood, pointed at both ends, to act as a brake when placed between the spokes of mine-car wheels. (3) The horizontal member of a square set of timber running longitudinally with the deposit.
Spragger.—One who attends to the spragging of cars.
Sprag Road.—A mine road having such a sharp grade that sprags are needed to control the speed of the car.
Spreader.—A timber stretched across a shaft or stope.
Spring Beams.—Two short parallel timber beams, built with a Cornish pumping engine house, nearly on a level with the engine beam, for catching the beam, etc., and preventing a smash in case of a breakdown.
Spring Latch.—The latch or tongue of an automatic switch, operated by a spring pole at the side of the track.
Spring Pole.—An elastic wooden pole from which boring rods are suspended. Used also to operate a spring latch.
Sprocket Wheel (English).—Rag wheel. A wheel with teeth or pins which catch in the links of a chain.
Spud, Spad.—A horseshoe nail with a hole in the head, for driving into the mine timbers, or into a wooden plug fitted into the roof, to mark a surveying station.
Spur.—(1) A short ridge or offsetting pointed branch from a main ridge or mountain. (2) A short branch or feeder from the main lode of a vein.
Square Set.—A variety of timbering for large excavations.
Squat (Cornish).—Tin ore mixed with spar.
Squeeze.—See *Creep.*
Squib.—A straw, rush, paper, or quill tube filled with a priming of gunpowder, with a slow match on one end.
Stage.—A platform on which mine cars stand.
Staging.—A temporary flooring or scaffold, or platform.
Stage Pumping.—Draining a mine by means of two or more pumps placed at different levels, each of which raises the water to the next pump above, or to the surface.
Stage Working.—A system of working minerals by removing the strata above the beds, after which the various beds are removed in steps or stages.
Stalactites.—Icicle-shaped formations of mineral matter depending from roof strata.
Stalagmites.—Accumulations of mineral matter that form on the floor, caused by the continual dripping of water impregnated with mineral matter.
Stall.—A narrow breast, or chamber.
Stall Gate.—A road along which the mineral worked in a stall is conveyed to the main road.
Stamp Mill, Stamps.—Machine for crushing ore.
Stanchion.—A vertical prop or strut.
Standage.—Pump reservoir.
Standing.—Not at work, not going forwards, idle.
Standing Gas.—A body of firedamp known to exist in a mine, but not in circulation; sometimes fenced off.
Standing Sett (English).—A fixed lift of pumps in a sinking set.

Stannary.—Tin works.
Staple.—(1) A shallow pit within a mine. (2) An underground shaft.
Starter.—A man who ascends a chute to the battery and starts the coal to running.
Starved (English).—When a pump is choked at the brass holes.
Station.—A plat or convenient resting place in a shaft or level.
Stave.—A ladder step.
Stay (English).—Props, struts, or ties for keeping anything in its place.
Steamboat Coal.—In anthracite only, coal small enough to pass through bars set 6 to 8 in. apart, but too large to pass through bars from $3\frac{1}{2}$ to 5 in. Comparatively few collieries make steamboat coal except to fill special contracts or orders.
Steam Coal.—A hard, free-burning, non-caking coal.
Steam Jet.—A system of ventilating a mine by means of a number of jets of steam, at high pressure, kept constantly blowing off from a series of pipes in the bottom of the upcast shaft.
Steel Mill.—An apparatus for obtaining light in a fiery mine. It consisted of a revolving steel wheel, to which a piece of flint was held, to produce sparking.
Steel Needle.—An instrument used in preparing blasting holes, before the safety fuse was invented.
Steening, or *Steining.*—The brick or stone lining of a shaft.
Stemmer.—A copper or wooden bar used for stemming.
Stemming.—(1) Fine shale or dirt put into a shot hole after the powder, and rammed hard. (2) Tamping a shot.
Step (English).—(1) The cavity in a piece for receiving the pivot of an upright shaft, or the end of an upright piece. (2) The shearing in a coal face.
Stint.—The amount of work to be done by a man in a specified time.
Stobb.—A long steel wedge used in bringing down coal after it has been holed.
Stockwork.—A rock run through with a number of small veins close together, the whole of which has to be worked when mining such deposits.
Stomp.—A short wooden plug fixed in the roof of a level, to serve as a bench mark for surveys.
Stone Coal.—Anthracite; also other hard varieties of coal.
Stone Head.—A heading or gangway driven in stone. A tunnel.
Stone Tubbing.—Water-tight stone walling of a shaft cemented at the back.
Stook.—A pillar of coal about 4 yd. square, being the last portion of a full-sized pillar to be worked away in bord-and-pillar workings.
Stook-and-Feather.—A wedge for breaking down coal, worked by hydraulic power, the pressure being applied at the extreme inner end of the drilled hole.
Stoop.—A pillar of coal.
Stoop-and-Room.—A system of working coal very similar to pillar-and-stall.
Stop.—Any cleat or beam to check the descent of a cage, car, pump rods, etc.
Stope.—(1) To excavate mineral in a series of steps. (2) A place in a mine that is worked by stoping.
Stoping.—Working out ore between two levels or on the surface, by stopes or steps. *Stoping Overhand.*—Mining a stope upwards, the flight of steps being inverted. *Stoping Underhand.*—Mining a stope downwards in such a series that it presents the appearance of a flight of steps.
Stopping.—An air-tight wall built across any passageway in a mine.
Stove Coal.—In anthracite only; two sizes of stove coal are made, large and small: large stove, known as No. 3, passes through a $2\frac{1}{4}''$ to $2''$ mesh and over a $1\frac{7}{8}''$ to $1\frac{1}{2}''$ mesh; small stove, known as No. 4, passes through a $1\frac{7}{8}''$ to $1\frac{3}{8}''$ mesh and over a $1\frac{1}{8}''$ to $1''$ mesh. Only one size of stove coal is now usually made. It passes through a $2''$ square mesh and over $1\frac{5}{8}''$ square mesh.
Stove Up, or *Stoved.*—Upset. When a rod of iron heated at one end is hammered endwise the diameter of that end is enlarged, and it is said to be upset.
Stow.—To pack away rubbish into goaves or old workings.
Stowce.—(1) Windlass. (2) Landmarks.
Stowing.—The débris of a vein thrown back of a miner and which supports the roof or hanging wall of the excavation.

Straight Ends and Walls.—A system of working coal somewhat similar to *bord-and-pillar.* Straight ends are headings from 4 ft. 6 in. to 6 ft. in width. Walls are pillars 30 ft. wide.
Straight Work.—A system of getting coal by headings or narrow work.
Strake.—A slightly inclined table for separating heavier minerals from lighter ones.
Stratification.—Arrangement in layers.
Stratum (plural, *strata*).—A layer or bed of rocks, or other deposit.
Streak.—The color of the mark made when a mineral is scratched against a white surface.
Strett.—The system of getting coal by headings or narrow work. See *Bord-and-Pillar.*
Strike (of a seam or vein).—The intersection of an inclined seam or a vein with a horizontal plane. A level course in the seam. The direction of strike is always at right angles to the direction of the dip of the seam.
Strike Joints.—Joints or cleavages that are parallel to the strike of the seam.
Striking Deal.—Planks fixed in a sloping direction just within the mouth of a shaft, to guide the tub to the surface.
Stringer (English).—Any longitudinal timber or beam.
Stringpump.—A system of pumping whereby the motion of the engine is transmitted to the pump by timbers or stringers bolted together.
String Rods.—A line of surface rods connected rigidly for the transmission of power; used for operating small pumps in adjoining shafts from a central station.
Strip.—(1) To remove the overlying strata of a bed or vein. (2) Mining a deposit by first taking off the overlying material.
Strut (English).—A prop to sustain compression, whether vertical or inclined.
Struve Ventilator.—A pneumatic ventilating apparatus consisting of two vessel-like gas holders, which are moved up and down in a tank of water. By this means, the air is sucked out of the mine as required.
Studdle.—A piece of squared timber placed vertically between two sets of timber in a shaft.
Stull.—A post for supporting the wall or roof in a mine; a prop timber.
Stump.—The pillar between the gangway and each room turned off the gangway. Sometimes the entry pillars are called stumps.
Stumping.—A kind of pillar-and-stall plan of getting coal.
Stup.—Powdered coke or coal mixed with clay.
Sturt.—A tribute bargain profitable to the miner.
Stuttle, or *Sprag.*—The horizontal member of a square set of timber running longitudinally with the deposit.
Stythe.—Carbonic-acid gas (blackdamp).
Sucker Rod.—The pump rod of an oil or artesian well.
Suction Pump (English).—A pump wherein, by the movement of the piston, water is drawn up into the vacuum caused.
Sulphur.—(1) One of the elements. (2) Iron pyrites.
Sulphuret.—See *Sulphide.*
Sulphide.—A combination of sulphur and a base.
Sump, or *Sumpt.*—A catch basin into which the drainage of a mine flows and from which it is pumped to the surface.
Surface Deposits.—Those that are exposed and can be mined from the surface.
Swab Stick.—A short wooden rod, bruised into a kind of stumpy brush at one end, for cleaning out a drill hole.
Swally, or *Swelly.*—A trough, or syncline, in a coal seam.
Swamp.—A depression or natural hollow in a seam. A basin.
Sweeping Table.—A stationary buddle.
Sweet.—Free from deleterious gases.
Sweet Roast.—To roast dead or completely.
Swing.—The arc or curve described by the point of an instrument, such as a pick or hammer, when being used.
Swinging Plate.—Amalgamated copper plates hung in sluices, to catch float gold.
Switch.—(1) The movable tongue or rail by which a train is diverted from one track to another. (2) The junction of two tracks. (3) A movable arm for changing the course of an electrical current.
Switchboard.—A board where several electrical wires terminate, and where, by means of switches, connection may be established between any of these wires and the main wire.
Swither.—A crevice branching from a main-lead lode.

Synclinal Axis.—The line or course of a syncline.
Syncline.—The point or axis of a basin toward which the strata upon either side dip. An inverted anticline. A basin.

Tackle (English).—(1) Ropes, chain, detaching hooks, cages, and all other apparatus for raising coal or ore in shafts. (2) Any rope for hoisting, as a tackle rope, block and tackle, etc.
Tahona (Mexican).—An arrastre moved by water-power. *Tahonero.*—The man in charge of the tahona.
Tail-Back.—When the firedamp ignites and the flame is elongated or creeps backwards against the current of air, it is said to tail-back.
Tailing.—The blossom; the outcrop or smut.
Tailings.—The detritus from reduction or gold-washing machinery.
Tail-Pipe.—The suction pipe of a pump.
Tailrace.—The channel along which water flows after it has done its work.
Tail-Rope.—(1) In a tail-rope system of haulage, the rope that is used to draw the empties back into the mine. (2) A wire rope attached beneath cages, as a balance.
Tail-Rope System of Haulage.—A haulage system in which the full trip is drawn out by the main rope, and the empty trip is drawn in by the tail-rope, these ropes being attached to the opposite ends of the trip (see page 400).
Tail-Sheave.—The sheave at the inbye end of any haulage system. See *Turn Pulley.*
Take the Air.—(1) To measure the ventilating current. (2) Applied to a ventilating fan as working well, or working poorly.
Taladro (Mexican).—A drill for mechanical or mining purposes. *Taladrar.*—To bore or drill.
Tally.—(1) A mark or number placed by the miner on every car of coal sent out of his place, usually a tin ticket. By counting these, a tally is made of all the cars of coal he sends out. (2) Any numbering, or counting, or memorandum, as a tally sheet.
Tamp.—To fill a bore hole, after inserting the charge, with some substance which is rammed hard as it is put into the hole. Vertical holes are often tamped with water, when blasting with dynamite.
Tamping.—The process of stemming or filling a bore hole.
Tamping Bar.—A copper-tipped bar, for ramming the tamping or stemming.
Tanates (Mexican).—Leather, hide, or jute bags, to carry ore or waste rock within or out of a mine. *Tanatero.*—A laborer or bag carrier.
Tap.—(1) To cut or bore into old workings, for the purpose of liberating accumulations of gas or water. (2) To pierce or open any gas or water feeder. (3) To win coal in a new district.
Tapextle (Mexican).—A working platform or stage built up in a stope or anywhere in a mine; a landing place between two flights of ladders.
Teem.—To pour or tip.
Teeming Trough.—A trough into which the water from a mine is pumped.
Telegraph.—A sheet-iron trough-shaped chute, for conveying coal or slate from the screens to the pockets, or boilers.
Tellurides.—Ores of the precious metals (chiefly gold) containing tellurium.
Temesquitale (Mexican).—The earthy part of ground-up ore.
Temper.—(1) To change the hardness of metals by first heating and then plunging them into water, oil, etc. (2) To mix mortar, or to prepare clay for bricks, etc.
Tempering.—The act of reheating and properly cooling a bar of metal to any desired degree of hardness.
Temper Screw.—In rope drilling, a screw for gradually lowering the clamped (upper) end of the rope as the hole is deepened.
Tenon.—A projecting tongue fitting into a corresponding cavity called a mortise.
Tentadura (Mexican).—An assay made in a horn spoon, an earthen saucer, or in a wide and shallow vessel of any kind, to ascertain the amount of amalgam present in a sample of argentiferous mud from an amalgamating patio. Any assay made by washing so as to concentrate the metallic portions of any mineral, and to cause the earthy portions to be floated off.
Tepetate (Mexican).—Any rock or earth found in a mine, which does not contain the metal sought for.

Tequio (Mexican).—A task set for a drillman or for any laborer in a mine, to be regarded as a day's work.
Terrace.—A raised level bank, such as river terraces, lake terraces, etc.
Terrero (Mexican).—The dump of a mine.
Test.—(1) A trial of an engine, fan, or other appliance or substance. (2) An iron framework that is filled with bone ash for cupeling on a large scale.
Theodolite.—An instrument used in surveying, for taking both vertical and horizontal angular measurements. An engineer's large transit, with attachments.
Thill.—See *Floor.*
Thimble.—(1) A short piece of tube slid over another piece, to strengthen a joint, etc. (2) An iron ring with a groove around it on the outside, used as an eye when a rope is doubled about it.
Thirl.—See *Crosscut.*
Through-and-Through.—A system of getting bituminous coal, without regard to the size of the lump.
Throw.—(1) A fault of dislocation. (2) The vertical distance between the two ends of a faulted bed of coal.
Thrown.—Faulted; broken by a fault.
Thrust.—Creep or squeeze due to excessive weight, hard floor, and too small pillars.
Thurl (Staffordshire).—To cut through from one working into another.
Ticketing.—English periodical markets for the sale of ores.
Tie-Back.—(1) A beam serving a purpose similar to a fend-off beam, but fixed at the opposite side of the shaft or inclined road. (2) The wire ropes or stayrods which are sometimes used on the side of the tower opposite the hoisting engine, in place of or to reenforce the engine braces.
Tierras (Spanish).—Earth impregnated with mercury ore.
Tierras de Labor (Mexican).—Dirt from a stope, mixed with particles of ore.
Tierras de Llunque (Mexican).—Chips made in breaking and sorting ore.
Tiff.—Calcite or carbonate of lime.
Timber.—(1) Props, bars, collars, legs, laggings, etc. (2) To set or place timber in a mine or shaft.
Timberer, *Timberman.*—A man who sets timber.
Time.—(1) Hours of work performed by workmen. (2) To count the strokes of a pump or revolutions of an engine or fan.
Tin-Can Safety Lamp.—A Davy lamp placed inside a tin can or cylinder having a glass in front, air holes near the bottom, and open-topped, making the lamp safer in a rapid current of air.
Tin-Witts (Cornish).—Product of first dressing of tin ores, containing, also, wolfram and sulphides.
Tip.—A dump. See *Tipper*, or *Tipple.*
Tipper, or *Tipple.*—An apparatus for emptying cars of coal or ore, by turning them upside down, and then bringing them back to original position. with a minimum of manual labor.
Tipple.—The dump trestle and tracks at the mouth of a shaft or slope, where the output of a mine is dumped, screened, and loaded.
Tiro (Mexican).—A mining shaft. *Tiro Vertical.*—A vertical shaft.
Token.—(1) A mutually understood mark placed upon a bucket of ore when it is hoisted or lowered into a shaft, to acquaint the lander or filler of some important matter. (2) A piece of leather or metal stamped with the hewer's or putter's number or distinctive mark, and fastened to the tub he is filling or putting.
Ton.—A measure of weight. Long ton is 2,240 lb.; short ton is 2,000 lb.; metric ton is 1,000 kilograms = 2,204.6 lb.
Top.—(1) See *Roof.* (2) Top of a shaft; surface over a mine.
Topit.—A kind of brace head screwed to the top of boring rods, when withdrawing them from the hole.
Torta (Mexican).—A pie or cake; the heaps of argentiferous mud that are treated in the patio process of amalgamation.
Tossing.—Shaking powdered ore in water, to effect separation of heavy and light particles.
Tovera (Mexican).—The tuyère of a smelting furnace.
Track.—Railways or tramways.
Tracking.—Wooden rails.
Train Boy.—A boy that rides on a trip, to attend to rope attachments, signal in case of derailment of cars, etc. Trip rider.

Train, or *Trip*.—The cars taken at one time by mules, or by any motor, or run at one time on a slope, plane, or sprag road, always together.
Tram.—A mine car, or the track on which it runs.
Trammer.—One who pushes cars along the track.
Tramroad.—A mine track or railroad.
Tram Rope.—A hauling rope, to which the cars are attached by a clip or chain, either singly or in trips.
Tramway.—A small, roughly constructed iron track for running wagons or trucks on.
Transfer Carriage.—Movable platform or truck used to transfer mine cars from one track to another.
Transome (English).—A heavy wooden bed or supporting piece.
Trap.—(1) A steep heading along which men travel. (2) A fault of dislocation. (3) An eruptive rock. (4) A dangerous place.
Trap Door.—A small door, kept locked, fixed in a stoping, for giving access to firemen and certain others to the return airways, dams, or other unused portions of the mine.
Trap Dike.—A fault (not necessarily accompanied by displacement of strata) in which the spaces between the fractured edges of the beds are filled up by a thick wall of igneous rock.
Trapiche (Spanish).—A primitive grinding mill.
Trapper.—A boy employed underground to tend doors.
Traveling Road.—An underground passage or way used expressly, though not always exclusively, for men to travel along to and from their working places.
Treenail.—A long wooden pin for securing planks or beams together.
Treloobing (Cornish).—Stirring tin slimes in water.
Trend.—The course of a vein, fault, or other feature.
Tribute.—A method of working mines by contract, whereby the miners receive a certain share of the products won. *Tributers*.—Miners paid by results.
Trig.—A sprag used to block or stop a wheel or any machinery.
Trilla (Mexican).—The same as *Torta*.
Trip.—The mine cars in one train or set. See *Train*.
Triple-Entry System.—A system of opening a mine by driving three parallel entries for the main entries.
Triturate.—To grind or pulverize.
Trolley.—(1) A small four-wheeled truck, used for carrying the ore bucket underground. (2) An electric motor. (3) The arm of a motor that conducts the electric current from the wire above the track to the machine.
Trommel.—A drum, consisting of a cylinder- or cone-shaped sheet-iron mantle (generally punched with holes) that revolves; used for washing or sorting ores.
Trompa (Mexican).—A funnel-shaped mouthpiece of cooled slag that forms within a smelting furnace over the tuyère opening.
Trompe.—An apparatus for producing ventilation by the fall of water down a shaft.
Trouble.—A dislocation or fault; any irregularity in the bed.
Trough Fault.—A wedge-shaped fault, or, more correctly, a mass of rock, coal, etc. let down in between two faults, which faults, however, are not necessarily of equal throw.
Troughs, or *Thirling*.—A passage cut through a pillar to connect two rooms.
Truck.—Used synonymously with *Barney*.
Truck System.—Paying miners in food instead of money.
Trunnions.—Cylindrical projections or journals, attached to the sides of a vessel, so that it can rotate in a vertical plane.
Trying the Lamp.—The examination of the flame of a safety lamp for the purpose of forming a judgment as to the quantity of firedamp mixed with the air.
Tub.—(1) A mine car. (2) An iron or wooden barrel used in a shaft, for hoisting material.
Tubbing.—Cast iron, and sometimes timber, lining or walling of a circular shaft.
Tubbing Wedges.—Small wooden wedges hammered between the joints of tubbing plates.
Tubing.—Iron pipes or tubes used for lining bore holes, to prevent caving.
Tumbar (Mexican).—To knock down ore, etc.
Tumbe (Mexican).—The act of knocking down and taking out ore.

Tunnel.—A horizontal passage driven across the measures and open to day at both ends; applied also to such passages open to day at only one end, or not open to day at either end.
Turbary.—A peat bog.
Turbine.—A rapidly revolving waterwheel, impelled by the pressure of water upon blades.
Turn.—(1) The hours during which coal, etc. is being raised from the mine. (2) See *Shift.* (3) To open rooms, headings, or chutes off from an entry or gangway. (4) The number of cars allowed each miner.
Turnout.—A siding or passing on any tram or haulage road.
Turn Pulley.—A sheave fixed at the inside end of an endless- or tail-rope hauling plane, around which the rope returns. See *Tail-Sheave.*
Turntable.—A revolving platform on which cars or locomotives are turned around.
Tut Work.—Breaking ground at so much per foot or fathom.
Tuyère.—The tubes through which air is forced into a furnace.
Two-Throw.—When, in sinking, a depth of about 12 ft. has been reached, and the débris has to be raised to the surface by two lifts or throws with the shovel, one man working on staging above another.
Tye.—An inclined table used for dressing ores.

Unconformability.—When one layer of rock, resting on another layer, does not correspond in its angle of bedding.
Undercast.—An air-course carried under another air-course or roadway.
Underclay.—A bed of fireclay or other less clayey stratum, lying immediately beneath a seam of coal.
Undercut.—To remove a small portion of the bottom of the bed or the underclay, so that the mass of coal or mineral can be wedged or blasted down.
Underhand Stoping.—See *Stoping Underhand.*
Underhand Work.—Picking or drilling downwards.
Underholing, Undermining.—To mine out a portion of the bottom of a seam or the underclay, by pick or powder, thus leaving the top unsupported and ready to be blown down by shots, broken down by wedges, or mined with a pick or bar.
Underlie, or *Underlay.*—The inclination of a lode at right angles to its course, or strike; the true dip.
Underviewer, or *Underlooker.*—An inside foreman.
Unit.—(1) The unit of metals is 1% of whatever ton is used. Generally, the 20-cwt. ton, equal to 2,240 lb., is employed, but, when dealing with copper ores, the 21-cwt. ton of 2,352 lb. is taken; therefore, the respective units are 22.4 lb. and 23.52 lb. (F. Danvers Powers). (2) Ores are quoted at a certain price per unit or per cent. of valuable material in the ore. If an iron ore contains 40% of metallic iron that is worth 5 cents per unit, the value of the ore is $2 per ton.
Unwater.—To drain or pump the water from a mine, or shaft.
Upcast.—The shaft through which the return air ascends.
Upraise.—An auxiliary shaft, a mill hole, or heading carried from one level up toward another.
Upthrow.—A fault in which the displacement has been upward.

Vapor (Mexican).—Steam; heated and stinking gas sometimes found in mines, which causes candles to burn dimly and go out.
Vaso (Mexican).—A reverberatory furnace used for smelting rich ore, or for cupeling silver.
Vat.—Large wooden tub used for leaching or precipitation.
Vein.—See *Lode.* Often applied incorrectly to a seam or bed of coal or other mineral.
Veinstone.—The non-metallic portion of a vein associated with the ore.
Vena (Mexican).—A thin vein, not over 3 in. thick—a knife-blade vein.
Vend (North of England).—Total sales of coal from a mine.
Vent, or *Vent Hole.*—(1) A small passage made with a needle through the tamping, which is used for admitting a squib, to enable the charge to be lighted. (2) Any opening made into a confined space.
Ventilating Column.—See *Motive Column.*
Ventilating Pressure.—The total pressure or force required to overcome the friction of the air in mines; the unit of ventilating pressure or pressure per sq. ft. of area multiplied by the area of the airway.
Ventilation.—Circulation. The atmospheric air circulating in a mine.

Ventilator.—Any means or apparatus for producing a current of air in mine or other airways.
Vestry (North of England).—A refuse.
Veta (Mexican).—A metalliferous vein of rock; a true fissure vein. Loosely, any mineral deposit. *Veta Clavada.*—A vertical vein. *Veta Echada.*—An inclined vein. *Veta Serpenteada.*—A vein with frequent changes of direction or course. *Veta Socia.*—A vein that joins another. *Veta Ramal.*—A branch vein. *Veta Recostada.*—An inclined vein.
Viewer.—The general manager or mining engineer of one or more collieries, who has control of the whole of the underground works, and also generally of those on the surface.
Vinney.—Copper ore with green efflorescence.
Vuelta (Mexican).—In refining silver, the moment when all impurities have been removed from the silver under treatment.
Vug, or *Vugh* (Cornish).—A cavity in the rock.

Wagon.—A mine car.
Wagon Breast.—A breast in which the mine cars are taken up to the working face.
Wailing.—Picking stones and dirt from among coals.
Wale (North of England).—Hand-dressing coal.
Walking Beam.—See *Working Beam.*
Wall.—(1) The face of a longwall working or breast. (2) A rib of solid coal between two breasts.
Walling.—See *Steening.*
Walling Cribs.—Oak cribs or curbs upon which walling is built.
Walling Stage.—A movable wooden scaffold suspended from a crab on the surface, upon which the workmen stand when walling or lining a shaft.
Wall Plates.—The two longest pieces of timber in a set used in a rectangular shaft.
Warners.—Apparatus consisting of a variety of delicately constructed machines, actuated by chemical, physical, electrical, and mechanical properties, for indicating the presence of small quantities of firedamp in the mines. At present, most of these ingenious contrivances are more suited to the laboratory than for practical application underground.
Warning Lamp.—A safety lamp fitted with certain delicate apparatus, for indicating very small proportions of firedamp in the atmosphere of a mine. As small a quantity as 3% can be determined by this means.
Wash.—Drift, clay, stones, etc. overlying the strata.
Washer.—A jig.
Wash Dirt.—That portion of alluvial working in which most of the gold is found.
Wash Fault.—A portion of a seam of coal replaced by shale or sandstone.
Washing Apparatus, or *Washery.*—(1) Machinery and appliances erected on the surface at a colliery, generally in connection with coke ovens, for extracting, by washing with water, the impurities mixed with the coal dust or small slack. (2) Machinery for removing impurities from small sizes of anthracite coal.
Washout.—The erosion of an appreciable extent of a coal seam by aqueous agency.
Wash Place.—A place where the ores are washed and separated from the waste, usually applied to places where the hand jigs are used.
Waste.—(1) See *Goaf.* (2) Very small coal or slack. (3) The portion of a mine occupied by the return airways. (4) Also used to denote the spaces between the pack walls in the gob of longwall working. (5) Refuse material.
Waste Gate (English).—A door for regulating discharge of surplus water.
Water Blast.—The sudden escape of air pent up in rise workings, under considerable pressure from a head of water that has accumulated in a connecting shaft.
Water Cartridge.—A waterproof cartridge surrounded by an outer case. The space between being filled with water, which is employed to destroy the flame produced when the shot is fired, thereby lessens the chance of an explosion should gas be present in the place.
Water Gauge.—An instrument for measuring the pressure per square foot producing ventilation in a mine.
Water Hammer.—The hammering noise caused by the intermittent escape of gas through water in pipes.

Water-Jacket.—A jacket filled with water, to keep cool a cylinder or furnace.
Water Level.—An underground passage or heading driven very nearly dead level or with sufficient grade only to drain off the water.
Water Right.—The privilege of taking a certain quantity of water from a watercourse.
Watershed.—The elevated land or ridge that divides drainage areas.
Waterwheel (English).—Overshot, undershot, breast wheels. A wheel provided with buckets, which is set in motion by the weight or impact of a stream of water.
Weather.—To crumble by exposure to the atmosphere.
Weather Door.—See *Trap Door.*
Web.—The face of a longwall stall in course of being holed and broken down for removal. The length of breast or face brought down by one mining.
Wedging.—The material, moss or wood, used to render the shaft lining tight.
Wedging Crib.—A curb or crib of wood or cast iron wedged tightly in place and packed, in order to form a water-tight joint and upon which tubbing is built.
Wedging Down.—Breaking down the coal at the face with hammers and wedges instead of by blasting.
Weeldon.—Old ironstone workings.
Weigh Bridge (English).—A platform large enough to carry a wagon, resting on a series of levers, by means of which heavy bodies are weighed.
Weize.—A band or ring of spun yarn, rope, rubber, lead, etc. put in between the flanges of pipes before bolting them together, in order to make a water-tight joint.
Well.—(1) The well of a furnace is the deepest lying portion or hollow in which the metal collects. (2) A sump, or a branch from the sump.
Whim.—A winding drum worked by a horse.
Whim Shaft.—A shaft through which coal, ore, water, etc. are raised from a mine by means of a whim.
Whin.—A hard, compact rock.
Whin Dike.—A fault or fissure filled with whin and the débris of other rocks, sometimes accompanied by a dislocation of the strata.
Whip.—A hoisting appliance consisting of a pulley supporting the hoisting rope to which the horse is directly attached.
Whitedamp.—Carbonic oxide (*CO*). A gas found in coal mines, generally where ventilation is slack. A product of slow combustion in a limited supply of air. It burns and will support combustion. It is extremely poisonous.
White Tin.—The commercial name for metallic tin.
Whits.—See *Tin-Witts.*
Whole Working.—The first working of a seam, which divides it into pillars.
Wild Lead.—Zinc-blende.
Wild Rock.—Any rock not fit for commercial slate.
Win.—To sink a shaft or slope, or drive a drift to a workable seam of mineral in such a manner as to permit its being successfully worked.
Winch, or *Windlass.*—A hoisting machine consisting of a horizonal drum operated by crank-arm and manual labor.
Wind Bore (England).—The bottom or suction pipe of a lift of pumps, which has suitable brass holes or perforations for suction of water or air.
Wind Gauge.—An anemometer, for testing the velocity of air in mines.
Winding.—The operation of raising or hauling by means of a steam engine and ropes, the product of a mine.
Winding Engines.—Hoisting or haulage engines.
Wind Method.—A system of separating coal into various sizes, and extracting the dirt from it, which in principle depends on the specific gravity or size of the coal and the strength of the current of air.
Wind Sail.—The top part of canvas piping, which is used for conveying air down shallow shafts.
Wing Bore.—A side or flank bore hole.
Wings.—See *Rests* and *Keeps.*
Winning.—A sinking shaft, a new coal, ironstone, clay, shale, or other mine of stratified material. A working place in a mine.
Winnowing Gold.—Air-blowing. Tossing up dry powdered auriferous material in the air, and catching the heavier particles not blown away.
Winze.—Interior shaft connecting levels, sometimes used as an ore chute.
Won.—Proved, sunk to, and tested.

Work.—(1) To mine. (2) Applied to mine working when affected by squeeze or creep.
Workable.—Any seam that can be profitably mined.
Worked Out.—When all available mineral has been extracted from a mine, it is worked out.
Working.—Applied to mine workings when squeezing.
Working Barrel.—The water cylinder of a pump.
Working Beam (English).—A beam having a vertical motion on a rock shaft at its center, one end being connected with the piston rod and the other with a crank or pump rod, etc.
Working Cost.—The total cost of producing the mineral.
Working Face.—See *Face.*
Working Home.—Getting or working out a seam of coal, etc., from the boundary or far end of the mine toward the shaft bottom.
Working on Air.—A pump works on air when air is sucked up with the water.
Working Out.—Working outwards or in the direction of the boundaries of the collieries.
Working Place.—The actual place in a mine at which the coal is being mined.
Workings.—The openings of a colliery, including all roads, ways, levels, dips, airways, etc.
Work Lead.—Base bullion, silver lead.
Wrought Iron.—Iron in its minimum state of carburization.
Wythern (Wales).—Lode.

Xacal (Mexican).—A miner's cabin; a storehouse for mining goods; a shaft house.

Yardage, Yard Work.—Price paid per yard for cutting coal.
Yard Price.—Various prices, per yard driven (in addition to the tonnage prices), paid for roads of certain widths, and driven in certain directions.
Yellow Ore (Cornish).—Chalcopyrite.
Yield.—The proportion of a seam sent to market.

Zone.—In coal-mining phraseology, this word means a certain series of coal seams with their accompanying shales, etc., which contain, for example much firedamp, called a fiery zone, or, if much water, a watery zone.

INDEX.

Coal — tons per acre per foot of thickness.

1 acre = 43560 sq ft
sp. gr. coal = 1.30
1 cu ft water = 62.5 lbs

Tons per acre $= \dfrac{43560 \times 1.3 \times 62.5}{2000}$

= 1769.62 or about
1770 tons per acre,
per ft in depth —

Tons per ft per sq mi =
1132800 tons

Fleming says coal per
acre per foot = 1630 tons but per ft
per sq mi = 1043200

Ordinary deduction for
loss is — per acre
per ft deep = 630 tons
per sq mi per ft = 403200
Reel says LaSalle region

Longwall can save
95% of all the coal,

In Herrin Quadrangle
33 1/3 - 50 per cent of the
6 coal seam is
left in the ground.